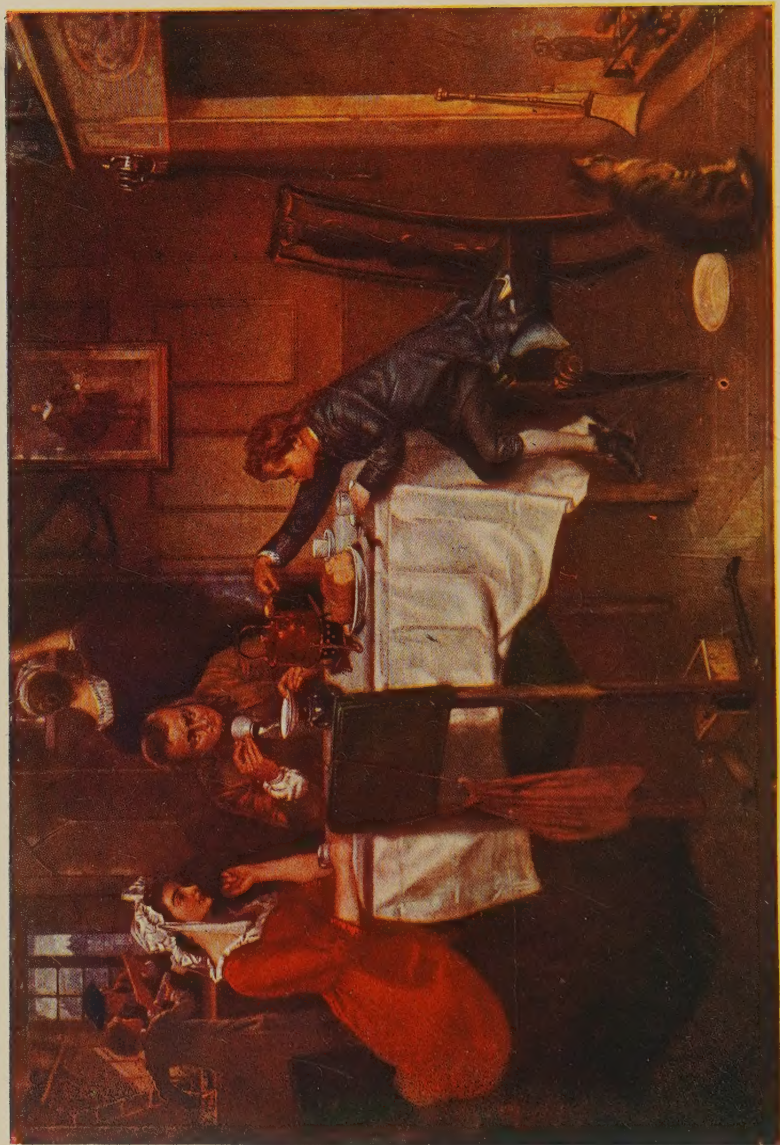


The
YOUNG FOLKS
TREASURY









WATT DISCOVERING THE POWER OF STEAM

YOUNG FOLKS' TREASURY

In 12 Volumes

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Editor

EDWARD EVERETT HALE

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Wonders of Science and Invention

HERBERT T. WADE

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INTRODUCTION

A COMPREHENSIVE review of the practical discoveries and striking generalizations of science which have in so many respects changed the outward forms of our civilization, places us in a position to sum up the achievements of the nineteenth century and compare them with what has gone before.

Taking first those inventions and practical applications of science which are perfectly new departures, and which have also so rapidly developed as to have profoundly affected many of our habits, and even our thoughts and our language, we find them to be thirteen in number.

1. Railways, which have revolutionized land travel and the distribution of commodities.

2. Steam navigation, which has done the same thing for ocean travel, and has besides led to the entire reconstruction of the navies of the world.

3. Electric telegraphs, which have produced an even greater revolution in the communication of thought.

4. The telephone, which transmits, or rather reproduces, the voice of the speaker at a distance.

5. Friction matches, which have revolutionized the modes of obtaining fire.

6. Gas lighting, which enormously improved outdoor and other illumination.

7. Electric lighting, another advance, now largely superseding gas.

8. Photography, an art which is to the external forms of nature what printing is to thought.

9. The phonograph, which preserves and reproduces sounds as photography preserves and reproduces forms.

10. The Röntgen rays, which render many opaque objects transparent, and open up a new world to photography.

11. Spectrum analysis, which so greatly extends our knowledge of the universe that by its assistance we are able to ascertain the relative heat and chemical constitution of the stars, and ascertain the existence, and measure the rate of motion, of stellar bodies which are entirely invisible.

12. The use of anæsthetics, rendering the most severe surgical operations painless.

13. The use of antiseptics in surgical operations, which has still further extended the means of saving life.

Now, if we ask what inventions comparable with these were made during the previous (eighteenth) century, it seems at first doubtful whether there were any. But we may perhaps admit the development of the steam engine from the rude but still useful machine of Newcomen to the powerful and economical engines of Boulton and Watt. The principle, however, was known long before, and had been practically applied in the previous century by the Marquis of Worcester and by Savery; and the improvements made by Watt, though very important, had a very limited result. The engines made were almost wholly used in pumping the water out of deep mines, and the bulk of the population knew no more of them, nor derived any more direct benefit from them, than if they had not existed.

In the seventeenth century, the one great and far-reaching invention was that of the telescope, which, in its immediate results of extending our knowledge of the universe and giving possibilities of future knowledge not yet exhausted, may rank with spectrum analysis in our own era. The barometer and thermometer are minor discoveries.

In the sixteenth century we have no invention of the first rank, but in the fifteenth we have printing.

The mariner's compass was invented early in the fourteenth century, and was of great importance in rendering ocean navigation possible and thus facilitating the discovery of America.

Then, backward to the dawn of history, or rather to prehistoric times, we have the two great engines of knowledge and discovery—the Indian or Arabic numerals leading to arithmetic and algebra, and, more remote still, the invention of alphabetical writing.

Summing these up, we find only five inventions of the first rank in all preceding time—the telescope, the printing press, the mariner's compass, Arabic numerals, and alphabetical writing, to which we may add the steam engine and the barometer, making seven in all, as against thirteen in our nineteenth century.

Coming now to the theoretical discoveries of our time, which have extended our knowledge or widened our conceptions of the universe, we find them to be about equal in number, as follows:

1. The determination of the mechanical equivalent of heat, leading to the great principle of the conservation of energy.
2. The molecular theory of gases.
3. The mode of direct measurement of the velocity of Light, and the experimental proof of the earth's rotation. These are put together, because hardly sufficient alone.
4. The discovery of the function of dust in nature.
5. The theory of definite and multiple proportions in chemistry.
6. The nature of meteors and comets, leading to the meteoritic theory of the universe.
7. The proof of the glacial epoch, its vast extent, and its effects upon the earth's surface.
8. The proof of the great antiquity of man.
9. The establishment of the theory of organic evolution.
10. The cell theory and the recapitulation theory in embryology.
11. The germ theory of the zymotic diseases.
12. The discovery of the nature and function of the white blood corpuscles.

Turning to the past, in the eighteenth century we may perhaps claim two groups of discoveries:

1. The foundation of modern chemistry by Black, Cavendish, Priestley, and Lavoisier; and

2. The foundation of electrical science by Franklin, Galvani, and Volta.

The seventeenth century is richer in epoch-making discoveries, since we have

3. The theory of gravitation established.

4. The discovery of Kepler's laws.

5. The invention of fluxions and the differential calculus.

6. Harvey's proof of the circulation of the blood.

7. Roemer's proof of finite velocity of light by Jupiter's satellites.

Then, going backward, we can find nothing of the first rank except Euclid's wonderful system of geometry, derived from earlier Greek and Egyptian sources, and perhaps the most remarkable mental product of the earliest civilizations; to which we may add the introduction of Arabic numerals, and the use of the alphabet. Thus in all past history we find only eight theories or principles antecedent to the nineteenth century as compared with twelve during that century. It will be well now to give comparative lists of the great inventions and discoveries of the two eras, adding a few others to those above enumerated.

OF THE NINETEENTH CENTURY.

1. Railways.
2. Steamships.
3. Electric telegraphs.
4. The telephone.
5. Lucifer matches.
6. Gas illumination.
7. Electric lighting.
8. Photography.
9. The phonograph.
10. The Röntgen rays.
11. Spectrum analysis.
12. Anæsthetics.
13. Antiseptic surgery.

OF ALL PRECEDING AGES.

1. The mariner's compass.
2. The steam engine.
3. The telescope.
4. The barometer and thermometer.
5. Printing.
6. Arabic numerals.
7. Alphabetical writing.
8. Modern chemistry founded.
9. Electric science founded.
10. Gravitation established.
11. Kepler's laws.

- | | |
|---|---|
| 14. Conservation of energy. | 12. The differential calculus. |
| 15. Molecular theory of gases. | 13. The circulation of the blood. |
| 16. Velocity of light directly measured, and earth's rotation experimentally shown. | 14. Light proved to have finite velocity. |
| 17. The uses of dust. | 15. The development of geometry. |
| 18. Chemistry, definite proportions. | |
| 19. Meteors and the meteoritic theory. | |
| 20. The glacial epoch. | |
| 21. The antiquity of man. | |
| 22. Organic evolution established. | |
| 23. Cell theory and embryology. | |
| 24. Germ theory of disease, and the function of the leucocytes. | |

Of course these numbers are not absolute. Either series may be increased or diminished by taking account of other discoveries as of equal importance, or by striking out some which may be considered as below the grade of an important or epoch-making step in science or civilization. But the difference between the two lists is so large that probably no competent judge would bring them to an equality. Again, it is noteworthy that nothing like a regular gradation is perceptible during the last three or four centuries. The eighteenth century, instead of showing some approximation to the wealth of discovery in our own age, is less remarkable than the seventeenth, having only about half the number of really great advances.

It appears then that the statement made by me elsewhere, that for adequate comparison with the nineteenth century we must take, not any preceding century or group of centuries, but rather the whole preceding epoch of human history, is justified, and more than justified, by the comparative lists now

given. And if we take into consideration the change effected in science, in the arts, in all the possibilities of human intercourse, and in the extension of our knowledge, both of our earth and of the whole visible universe, the difference shown by the mere numbers of these advances will have to be considerably increased on account of the marvelous character and vast possibilities of further development of many of our recent discoveries.

ALFRED R. WALLACE

NOTE BY EDITOR

From a summary of nineteenth-century progress by Professor Ludwig Büchner, of Germany, we take the following passages, which supplement Professor Wallace's statements:

"The improved telescopes of the present time have provided us with such an intimate knowledge of the constitution of the surface of our moon that it is now better known than some parts of the surface of the earth—as in the interior of the great continents of Africa, Australia, and America. Similar information, though to be taken with reserve, was obtained from the remarkable phenomena observed on the surface of the planet Mars. The interpretation of these features has not been thus far absolutely settled, but in the opinion of eminent astronomers they indicate the presence on that planet of thinking beings. [Further reference to this subject will be found in the section on Astronomy.] To the nineteenth century also belongs the older discovery of the planet Neptune, which was made in such a wonderful way by Adams, Leverrier and Galle in 1846. This discovery must be regarded as one of the greatest triumphs of astronomical science, since it was the fruit of a demonstration by mathematical calculations of the existence of a heavenly body, while the actual finding and identification of it were achieved afterward by means of the telescope.

“As with respect to material progress the past century is fittingly called the century of steam, so most likely the twentieth will have to be designated the century of electricity, when the more extended control of the forces of nature by the human mind shall have taken an immense stride in the forward direction. If we add to all this that the grand material as well as intellectual development of the great land of liberty in the far West of our globe, the like of which has never been seen before, promises to continue in the same or even a higher degree, then the men of the new century will of necessity be more profoundly impressed than the children of the present by the achievements of human intellect and human power.”

In no small measure the twentieth century started to verify this prophecy. But soon came a rude awakening. Science so long the handmaiden of peace and industry became the servant of grim war, and engineer, electrician, chemist, and other men of science united in the sad task of destruction, where but a few years since they had sought to uplift mankind, and to utilize the forces of nature. Almost alone surgeon and sanitarian stood ready with new inventions and kindly skill to repair the sad damage. Yet not in vain did the husbandman call in science to help him wrest from the soil the added sustenance that his brothers needed and would gladly have earned were they not intent on destruction. But ere this rude interlude to the earth's drama opened, the twentieth century had much to its credit. The aeroplane and dirigible had conquered the air. Anti-toxins and vaccines had removed many a scourge. The submarine was an important engine of war. The motor vehicle, made feasible by the perfection of the internal combustion engine universally had changed our modes of life. The electric furnace had brought new and useful alloys, while high speed steels had revolutionized machine work. The wireless telephone and telegraph represented still another triumph by man, and the study of astrophysics had placed on a firm basis our ideas of the sun and other heavenly bodies.

MODES OF TRAVELING

Primitive and Modern Locomotion

By ALFRED RUSSEL WALLACE

WE men of the nineteenth century have not been slow to praise it. The wise and the foolish, the learned and the unlearned, the poet and the pressman, the rich and the poor, alike swell the chorus of admiration for the marvelous inventions and discoveries of our own age, and especially for those innumerable applications of science which now form part of our daily life, and which remind us every hour of our immense superiority over our comparatively ignorant forefathers.

But though in this respect (and in many others) we undoubtedly think very well of ourselves, yet, in the opinion of the present writer, our self-admiration does not rest upon an adequate appreciation of the facts. In order to estimate its full importance and grandeur—more especially as regards man's increased power over nature, and the application of that power to the needs of his life to-day, with unlimited possibilities in the future—we must compare it, not with any preceding century, or even with the last millennium, but with the whole historical period—perhaps even with the whole period that has elapsed since the stone age.

Looking back through the long dark vista of human history, the one step in material progress that seems to be really comparable in importance with several of the steps we have just made, was, when Fire was first utilized, and became the servant and the friend instead of being the master and the enemy of man. From that far distant epoch even down to our day, fire,

in various forms and in ever-widening spheres of action, has not only ministered to the necessities and the enjoyments of man, but has been the greatest, the essential factor, in that continuous increase of his power over nature, which has undoubtedly been a chief means of the development of his intellect and a necessary condition of what we term civilization. Without fire there would have been neither a bronze nor an iron age, and without these there could have been no effective tools or weapons, with all the long succession of mechanical discoveries and refinements that depended upon them. Without fire there could be no rudiment even of chemistry, and all that has arisen out of it. Without fire much of the earth's surface would be uninhabitable by man, and much of what is now wholesome food would be useless to him. Without fire he must always have remained ignorant of the larger part of the world of matter and of its mysterious forces. He might have lived in the warmer part of the earth in a savage or even in a partially civilized condition, but he could never have risen to the full dignity of intellectual man, the interpreter and master of the forces of nature.

Having thus briefly indicated our standpoint, let us proceed to sketch in outline those great advances in science and the arts which are the glory of our century. In the course of our survey we shall find that the more important of these are not mere improvements upon, or developments of, anything that had been done before, but that they are entirely new departures, arising out of our increasing knowledge of and command over the forces of the universe. Many of these advances have already led to developments of the most startling kind, giving us such marvelous powers, and such extensions of our normal senses, as would have been incredible, and almost unthinkable even to our greatest men of science, a hundred years ago. We begin with the simplest of these advances, those which have given us increased facilities for locomotion.

The younger generation, which has grown up in the era of railways and of ocean-going steamships, hardly realize the vast change which we elders have seen, or how great and fundamental that change is. Even in my own boyhood the wagon

for the poor, the stage coach for the middle class, and the post-chaise for the wealthy, were the universal means of communication, there being only two short railways then in existence—the Stockton and Darlington opened in 1825, and the Liverpool and Manchester line opened in 1830. The yellow post-chaise, without any driving seat, but with a postilion dressed like a jockey riding one of the pair of horses, was among the commonest sights on our main roads; and together with the hundreds of four-horse mail and stage coaches, the guards carrying horns or bugles which were played while passing through every town or village, gave a stir and liveliness and picturesqueness to rural life which is now almost forgotten.

When I first went to London (about 1835) there was still not a mile of railroad in England, except the two above named, and none between London and any of our great northern or western cities were even seriously contemplated. The sites of most of our great London railway termini were then on the very outskirts of the suburbs.

A few years later, while the London and Birmingham Railway, the precursor of the present London and Northwestern system, was in process of construction; and when the first section was opened to Watford, I traveled by it to London, third-class, in what is now an ordinary goods truck, with neither roof nor seats, nor any other accommodation than is now given to coal, iron, and miscellaneous goods. If it rained, or the wind was cold, the passengers sat on the floor and protected themselves as they could. Second-class carriages were then what the very worst of the third class are or were a few years ago—closed in, but low and nearly dark, with plain wooden seats—while the first-class were exactly like the bodies of three stage coaches joined together. The open passenger trucks were the cause of much misery, and a few deaths from exposure, before they were somewhat improved; but even then there was evidently a dread of making them too comfortable, so a roof was put to them, also seats, and the sides a little raised but open at the top, about equal in comfort to our present cattle trucks. At last, after a good many years, the despised third-class passengers were actually provided with carriages of the early sec-

ond-class type; and it is only in comparatively recent times that the greater railway companies realized the fact that third-class passengers were so numerous as to be more profitable than the other two combined, and that it was worth while to give them the same comfort, if not the same luxury, as those who could afford to travel more expensively.

The continuous progress in speed and comfort is matter of common knowledge, and nothing more need be said of it here. The essential point for our consideration is, the fundamental and even revolutionary nature of the change that has been wholly effected during the present century. In all previous ages the only modes of traveling or of conveying goods for long distances were by employing either men or animals as the carriers. Wherever the latter were not used, all loads had to be carried by men, as is still the case over a large part of Africa, and as was the case over almost the whole of America before its discovery by the Spaniards.

But throughout Europe and Asia the horse was domesticated in very early times, and was used for riding and in drawing war-chariots; and throughout the Middle Ages pack-horses were in universal use for carrying various kinds of goods and produce, and saddle horses for riding. All journeys were then made on horseback, and it was in comparatively recent times that wheeled vehicles for traveling came into general use in England. The very first carriage was made for Queen Elizabeth in 1568; the first that plied for hire in London were in 1625, and the first stage coaches in 1659.

But chariots drawn by horses were used, both in war and peace, by all the early civilized peoples. Pharaoh made Joseph ride in a chariot, and he sent wagons to bring Jacob, with his children and household goods, to Egypt. A little later, chariots were sent by the Syrians as tribute to Pharaoh. Homer describes Telemachus as traveling from Pylos to Sparta in a chariot provided for him by Nestor:

The rage of thirst and hunger now suppress'd,
The monarch turns him to his royal guest;
And for the promis'd journey bids prepare
The smooth-haired horses, and the rapid car.

It is clear, therefore, that in the earliest historic times all the various types of wheeled vehicles were used—for war, for racing, for traveling, and for the conveyance of merchandise. They must also have been used throughout a large part of Europe, since Cæsar found our British ancestors possessed of war-chariots, which they managed with great skill, implying a long previous acquaintance with the domesticated horse and its use in humbler wheeled vehicles.

Thus, throughout all past history the modes of traveling were essentially the same, and an ancient Greek or Roman, Egyptian or Assyrian, could travel as quickly and as conveniently as could Englishmen down to the latter part of the eighteenth century. It was mainly a question of roads, and till the beginning of the nineteenth century our roads were for the most part far inferior to those of the Romans. It is, therefore, not improbable that during the Roman occupation of Britain the journey from London to York could have been made actually quicker than a hundred and fifty years ago.

We see, then, that from the earliest historic, and even in prehistoric times, till the construction of our great railways in the second quarter of the present century, there had been absolutely no change in the methods of human locomotion; and the speed for long distances must have been limited to ten or twelve miles an hour even under the most favorable conditions, while generally it must have been very much less. But the railroad and steam-locomotive, in less than fifty years, not only raised the speed to fifty or sixty miles an hour, but rendered it possible to carry many hundreds of passengers at once with punctuality and safety for enormous distances, and with hardly any exposure or fatigue. For the civilized world traveling and the conveyance of goods have been revolutionized, and by means which were probably neither anticipated nor even imagined fifty years before.

Dr. Erasmus Darwin, who predicted steam carriages, had apparently no conception of the possibility of railroads, the enormous cost of which would have seemed to be prohibitory. And we have by no means yet fully developed their possibilities, since even now a railroad could be made on which we

might safely travel more than a hundred miles an hour, it being merely a question of expense.

In steam navigation there has been a very similar course of events, with the same characteristic of a completely new departure, leading to unknown developments and possibilities. From the earliest dawn of history, men used rowing or sailing vessels for coasting trade or for crossing narrow seas. The Carthaginians sailed nearly to the equator on the west coast of Africa, and in the eleventh century the Northmen reached North America on the coast of New England. Over five hundred years ago, Vasco de Gama sailed from Portugal round the Cape of Good Hope to India, and in the next century Columbus and his Spanish followers crossed the Atlantic in its widest part to the West Indies and Mexico. From that time sailing ships were gradually improved, till they culminated in our magnificent frigates for war purposes and the clipper ships in the China and Australian trade, which were in use up to the middle of the century. But during all this long course of development there was no change whatever in principle, and the grandest three-decker or full-rigged clipper ship was but a direct growth, by means of an infinity of small modifications and improvements, from the rudest sailing boat of the primeval savage.

Then, at the very commencement of the present century, the totally new principle of steam propulsion began to be used, first experimentally and with many failures, on rivers, canals, and lakes, till about the year 1815 coasting steamships of small size came into pretty general use. These were rapidly improved; but it was not till the year 1838 that the Great Western, of 1,340 tons and four hundred horse-power, made the passage from Bristol to New York in fourteen days, and thus inaugurated the system of ocean steam navigation which has since developed to such an enormous extent. The average speed then attained, of about ten miles an hour, has now been more than doubled, and is still increasing. But the horse-power needed to attain this high speed has increased in much greater proportion; and it is only the much greater size and capacity, both for passengers and goods, that render such high

speeds and enormous consumption of coal profitable. Some of the smaller steel-built war-ships — torpedo-boats and torpedo-destroyers — have considerably exceeded thirty miles an hour, and the limit of speed is probably not yet reached. Many suggested forms of vessels, such as the cigar-shaped and the roller boats, have not been adequately tried; and there are other suggested forms by means of which greater steadiness and speed may yet be obtained.

Almost as remarkable as our railroads and steamships is the new method of locomotion by means of the bicycle and tricycle. The greatest possibilities are with the bicycle, driven by electric power or compressed air, by which means, on a nearly straight and fairly level asphalt track, no doubt fifty miles an hour will soon be reached.

We see, then, that during the nineteenth century three distinct modes of locomotion have been originated and brought to a high degree of perfection. Two of them, the locomotive and the steamship, are altogether different in principle from what had gone before. The principles on which our present methods rest are new; they already far surpass anything that could be effected by the older methods; with wonderful rapidity they have spread over the whole world, and they have in many ways modified the habits and even the modes of speech of all civilized peoples.

This vast change in the methods of human locomotion, already so ubiquitous that by the younger generation their absence rather than their presence is considered remarkable, has been almost wholly effected within the writer's memory.

EDITOR'S NOTE. — Dr. Wallace before his death in 1913 also was able to see developed for the twentieth century three additional modes of locomotion. The power-driven bicycle for high speed travel had become the motor vehicle of universal use and application. Not only had the racing car attained a rate of some 80 or more miles an hour, but the ordinary passenger or commercial vehicle was operated on ordinary roads with a speed rivaling the ordinary railway. The conquest of the air had been achieved, and

prior to the great European conflict, Zeppelin dirigibles were engaged in regular passenger service and their possibilities for transoceanic travel clearly had been demonstrated. Although the aeroplane had not reached the point where it was universally applied in commercial use, war conditions soon placed it on a practical footing for military purposes, both for observation and offense.

The twentieth century also demonstrated that travel was not confined to the surface of the great ocean, but when interfered with by war could be conducted under sea. Not only was the submarine an engine of destruction, but as was shown when the German *Deutschland* made commercial trips to the United States during the war, it had the other important uses of avoiding hostile blockades and the activity of enemy cruisers.

At the time of Dr. Wallace's death travel on land had reached a high degree of comfort and speed through the development of the steam locomotive and by the use of electric railways. By 1917 over 2,500 miles of American trunk lines had been electrified, and on one railway line, the Chicago, Milwaukee and Saint Paul, 440 miles were in operation with plans developed for 250 miles further.

On the ocean, size and speed of vessels had increased so that just before the outbreak of the great European war the German liner *Vaterland*, 950 feet in length, of 61,000 tons displacement and with an ocean speed of 24 knots, represented the last word in trans-Atlantic navigation. After the triple expansion engine came the steam turbine, and for smaller craft the internal combustion engine. Fuel oil was enjoying advantages over coal, and the first vessel to carry supplies for the American army in Europe in 1917 was a collier fitted with electric drive.

New problems of transportation indeed had been solved in the nineteenth century, and for the twentieth no less important and radical innovations were destined to be developed by science and invention.

MODES OF TRAVELING

The Motor Vehicle

By HERBERT T. WADE

PERHAPS it has never occurred to us to inquire the name of the man who first suggested mechanical locomotion. The idea is by no means new. That keen-witted Franciscan friar, Roger Bacon (1214-1294), who hazarded many a shrewd prophecy as to mechanical developments was able to look forward with clear vision to a horseless age, and in the quaint Latin of the *Opus Majus*, a thirteenth century encyclopædia, he wrote, "We will be able to propel carriages with incredible speed without the assistance of any animal." Sir Isaac Newton in 1680 proposed a machine where a spherical steam boiler was mounted on a carriage that carried also a coal furnace. The steam issued from a pipe at the rear of the boiler and by its reaction upon the carriage drove the vehicle forward, while the driver, with a lever and cock, regulated the amount of steam discharged and thereby the speed of the vehicle.

The trail of vapor coming from behind such a vehicle in the illustration of Newton's writings is strangely familiar in these days, where too many cars can be trailed by the smoke at the exhaust, and we can only wonder whether in the event of the realization of such a steam vehicle the traffic police of that day would have haled the discoverer of gravitation before a magistrate.

In the development of the steam engine not a few investigators suggested its application to mechanical locomotion and probably with the idea of great speed and power a "fiery

chariot" was advanced as a mechanical possibility by Dr. Erasmus Darwin, the philosopher, in 1765, and a set of plans were prepared by this distinguished genius. But Europe was not the only place where such thoughts were held and in 1790 a United States patent was issued for a steam carriage to Nathan Read, a graduate of Harvard College, in which was incorporated a special type of water-tube boiler, but the distinguished inventor never constructed anything more than a model.

In France, Nicholas Joseph Cugnot, a French mechanic, in 1769-70 had built two steam carriages, the latter of which was preserved in the Conservatoire des Arts et Métiers of Paris. It had a single wheel in front driven by two single acting engines, and the boiler was placed in front of the cylinders, which were thirteen inches in diameter. The locomotive was designed for the transportation of artillery, and thus attracted the attention of Napoleon Bonaparte, and in its application of power to the front wheels, in the arrangement of the driver's seat, and in many other respects suggested various devices of the present-day tractor. This first French road locomotive failed on account of the inefficiency of the feed pumps, but the second was designed on a reasonably satisfactory basis, except as regards the small size of the boiler and the fact that the steering apparatus could not handle the carriage with promptness.

The American inventor, Oliver Evans, also had in mind the construction of a steam-carriage and he actually built a steam dredging machine which, weighing 4,000 pounds, was propelled by its own engine through the streets of Philadelphia to the Schuylkill River, where it was launched. The engine was subsequently connected with a stern paddle-wheel.

One after another various inventors with more or less success made various forms of steam-carriages, and a carriage of fair size, built by Trevithick and Vivian at Camborne, England, in 1803, was driven by its own engine from Camborne to Plymouth. Again, in 1821, Joseph Bramah, one of the foremost mechanics and locksmiths of England, built a carriage which was used experimentally for a number of years,

but failed as a practical achievement on account of the limited capacity of the boiler.

With the development of the steam-engine various improvements naturally were made in the different steam-carriages, and in 1831 a number of steam-carriages were in actual operation on various routes in England, and speeds of from thirty-two to thirty-five miles an hour were accomplished. One of the most notable of these was the steam-coach built by W. Hancock, called by its inventor the "Autopsy," which notwithstanding its gruesome name was a pronounced success and was maneuvered in the crowded streets of London without the slightest difficulty, making on regular routes an average speed of twelve miles an hour. In December, 1833, in or near London, there were some twenty steam carriages and traction road engines in operation or in course of construction.

The excellent character of the English roads was an important element in the development of road engines, whereas in the United States the poorly built and maintained highways did not offer inducements to American inventors and mechanics to undertake the development of mechanical carriages. The work thus promisingly started in England, met with a serious setback on account of the rapid development of railways, and hostility to the use of the public highways by steam-cars; in fact, this tendency was manifested for many years and it was only toward the end of the nineteenth century that legislation seriously restricting all forms of mechanical vehicles was done away with, and the regulation requiring a man with a red flag to proceed in front of a mechanical tractor or other vehicle abolished. In the meantime on the Continent, especially in France, great strides had been made in the motor-car, and as a result the English industry was late in beginning and has never equalled either in quality or extent that of Europe or of the United States.

On the Continent of Europe the invention of the gas-engine or internal combustion motor by M. Beau de Rochas in 1862 led to the greatest interest in the development of this form of prime mover, and it was not strange that in 1886

Gottlieb Daimler, of the Otto Gas Engine Works at Deutz, and Carl Benz, another German engineer, should seek to apply the gas-engine to light road vehicles. Daimler suggested a motor where the cylinders were cooled by air after each explosion, while Benz devised a small water-cooled motor.

From this time the growth of the use of the automobile was as rapid as it was constant. As a sport it interested and amused its votaries. The thrilling and often fatal races were watched by thousands as successively records for road and track were reduced. But early it was realized that there were many other points than high speed and sport to be considered. It straightway developed that here were economies in maintenance and operation that appealed no less to the owner of a carriage than to the owner of the hackney cab of the city streets and to the shopkeeper whose customers demanded prompt and even suburban deliveries. The pleasure of touring the country without fear of fatigue to horse flesh or limit of distance soon attracted many more quiet people to whom the deadly road race or mile-a-minute driving, with manifest danger to the cars and their occupants, as well as to other users of the highway, did not make the slightest appeal. Added to these classes were those to whom mechanism and its control exercised a certain subtle fascination. These and other causes contributed toward putting motoring on a sound and permanent basis and toward establishing industries that in every civilized country rank high among the manufactures.

It is a mechanical age in which we are living, and the touchstone of efficiency and economy must be used to test our modes of life, and mechanism must take the place of human and animal effort whenever economic conditions dictate. If one mechanically propelled delivery truck can do as much work as three teams of horses in a business day with one driver instead of three and at a less cost of maintenance, it is obvious that as a matter of business an increased outlay for an automobile vehicle is more than justified; it is demanded.

But this we are told is very commonplace. Any metropolitan dweller may see taxicabs, motor trucks and touring

cars innumerable. Almost every prosperous farmer now owns and runs a motor car, at least one of limited size and power, and the annihilation of space and time goes on in our every-day life, on our streets, roads, and lanes, as it does on our railway and telegraph lines.

The farmer or superintendent whose work carries him to different places must not take valuable time in mere traveling as he goes about his necessary errands or duties. He must either toil himself or supervise the labor of others, and if he is able to go speedily from one point to another where work is being carried on, it is obvious that the work will be done more effectively. With the high cost of farm labor and horses their time should not be spent unprofitably when an ever ready motor car of hardly more than the same cost is available, untired and able to go the distance in a fraction of the time. A country physician can make more visits and can see more distant patients, and thus can take better care of the sick than could his predecessor in the familiar chaise or buggy whose horse or horses might be spent before the daily rounds were completed.

For most purposes of travel the motor long since has supplanted the horse, particularly when questions of time and amount of service are concerned. In almost all instances superior economy is shown for the motor vehicle, and it is only on the farm that the horse figures, speaking broadly, and even now the mechanical tractor made in small sizes threatens to deprive him of this service.

To-day the American automobile represents the triumph of metallurgical science, mechanical engineering, business organization, and general efficiency of manufacturing. Cars are made by the thousand with as much care and attention as is given to watch-making, and the parts are absolutely interchangeable, so that in the best factories perfect fitting cars can be assembled from stock parts without the necessity for the slightest fitting or adjustment, while other manufacturers stand ready to supply parts from which cars can be assembled.

The strongest and best steels and alloys are used for the

special parts, and chemical analyses, tests, and experimentation to find the best material for any specific purpose are constantly carried on. There is no department of mechanical engineering to-day where the materials of construction undergo more rigid tests before acceptance than in an automobile factory.

As a result of modern methods of manufacturing a large number of pleasure cars, capable of giving general satisfaction and good wear, are listed at from \$1,000 to \$2,500, while useful cars capable of good service, though of course smaller and less powerful, are sold at between \$400 and \$1,000.

In 1893 the motor-propelled vehicle was a matter of experiment in the hands of those who could see its possibilities. In 1899 the manufacture of automobile vehicles began to assume the dignity of an industry, and three years later an output of some 9,000 machines was recorded. Contrast this with 1,617,708 motor vehicles produced in 1916. The total number of cars registered throughout the United States at the end of 1916 was approximately 3,500,000, so that in round figures for every thirty inhabitants of the nation there was one automobile.

These figures are indeed startling, and the development of the national industry further is shown by the fact that whereas in 1902 America was importing many motor vehicles, in 1916 it had become the largest automobile exporting nation of the world, its outputs in that year being valued at \$120,000,000, to practically every quarter of the globe.

It is interesting to note that the automobile no longer is a rich man's plaything. In 1916 the average retail price of a passenger car was \$605 as compared with \$2,123 in 1907, and \$1,284 in 1899 for the steam runabouts, which were practically the forerunners of the pleasure automobile in the United States, though their vogue was of comparatively limited duration. With a decrease in price there has resulted an increased efficiency in the cars made, and irrespective of price there has been achieved a perfection in processes of manufacture as well as in the details of the

machines themselves. Obviously the runabout selling for \$500 has not the strength and power of a twin-six cylinder car costing \$5,000 or more, but the fields of the two are entirely different, as are the costs of maintenance, and each is designed for the taste and purse of a special class of purchasers.

The operating expense of a pleasure vehicle varies considerably under different conditions. The cost of running naturally depends upon the amount of use, the skill of the chauffeur, and the care that the engine and car receive. The wear on the engine depends upon the care it receives, particularly on whether it is kept well lubricated, and to a certain extent upon the skill with which it is operated in actual driving. The price of tires naturally depends upon the cost of crude rubber in the markets of the world, while the price of gasoline, which seems always to be mounting, is influenced by economic considerations. For these reasons many people prefer to drive a lighter car with a smaller fuel consumption and less wear on the tires. An American buyer with literally hundreds of styles of cars of various types and prices to select from is able to suit his means and inclinations provided he realizes at the outset just what his needs are.

Having considered the economic side of the motor vehicle let us pay a few minutes' attention to its mechanism. We should like to understand how the gasoline automobile is operated. A friend asks us for a ride in his car, a well-appointed and handsome affair of polished metal and shining varnish. All but concealed is the machinery, and as we enter and take our seat by the driver, we notice that the turn of a button and the pressure of a foot on the pedal is all that is required to move the car silently along the highway, where we make our presence known and warn pedestrians at the cross-walks by the familiar honk-honk of our horn.

Perhaps we had noticed that our friend the driver had stopped where there was a familiar red pump to fill his tanks under the cushions or at the rear of the car with a

colorless fluid having a slight but pungent odor, and noticed that before he did so he threw away his lighted cigarette. Into the tanks was being poured a volatile liquid with an inflammable vapor that had been derived from the petroleum wells of such districts as Pennsylvania, Oklahoma, Indiana, Ohio, California, and Texas. The crude oil had been distilled and purified and some eight to ten per cent had been obtained in the form of highly volatile products — naphtha, benzine, and gasoline. For the motor car the last named substance is preëminently useful and it is universally sold wherever the ordinary facilities of transportation permit its shipment. In fact, to-day the possible exhaustion of supplies of crude petroleum is a serious cause of alarm, not only to the motorist and the automobile industry but to the community generally, and successive advances in the price of gasoline by many are considered omens of future famine. New processes of “cracking” the petroleum and of condensing natural gas to obtain gasoline have been tried with more or less success, but still the demand continues to grow.

In the distillation of petroleum there are obtained other fuels far less volatile than gasoline, such as kerosene, and it is the ambition of the automobile engine designer to produce a device whereby such lower grade fuels not sufficiently volatile to vaporize themselves can be heated and vaporized. The problem is not impossible and a number of suggestions for its solution, more or less practical, have been made. For example, it has been proposed to use a separate supply of gasoline merely for starting the engine and then rely on the kerosene for running it, for once the engine is running it is of course possible to use the exhaust to heat the fuel. It was also suggested that an independent oil burner be used at the beginning of the operation and experiments have been undertaken in this field. Nevertheless, while the quality of gasoline available for motorists has steadily declined, at the same time the carbureters on the general run of cars have been so improved that they will use lower grades.

In the steam-engine we burn the fuel under a boiler containing water to produce steam and use its expansive force to produce power. In the internal combustion motor we burn the fuel, but the combustion is very rapid, in fact like that rapid combustion of gunpowder we call an explosion, and the energy is produced by the expansion of gases that are the products of combustion.

First there is required a material that burns or explodes readily and with sufficient force, then some place where the explosion can take place and where there is a piston or some moving part against which the expansive force comes, some means of producing the explosion, and finally the mechanism for transforming into useful work of the nature desired, the movement of the piston. Now it is not the gasoline itself that is so combustible, but a mixture of it vaporized with a certain amount of air. If we fill the cylinder full with gasoline we would have no explosion when we introduced a flame or spark, and if we did we would have a consumption of fuel that would carry us but a little distance.

Now, it is only a small amount of gasoline that is needed, for in the form of vapor it is united with a considerable volume of air to form a very explosive mixture. This takes place in what is known as the carbureter into which the gasoline from the tank is sprayed into a small chamber where it mixes with the air and passes into the combustion cylinders. Here the explosion takes place and the piston is forced down the cylinder as the gases expand just as the projectile is forced along the bore of the gun by the explosion of the powder.

The motion of the piston is communicated to a crank turning over the main shaft, and communicates its motion through gearing to the rear wheels. There may be two, four, or six cylinders arranged vertically, or in later models the cylinders may be grouped in pairs at an angle so that there may be eight or twelve cylinders with pistons acting on a single crankshaft. Whatever the arrangement or number of cylinder pistons the cranks, cams, and valves are

arranged so that the explosions shall take place successively and evenly, a smooth, even rotary motion being given to the crankshaft. This is connected by gears, which may be shifted at will by the driver so that while the main shaft is revolving at a certain speed, by the time the motion reaches the wheels through the gearing and other features of the transmission its speed is reduced and its power increased. The gears also are arranged so that the motion is reversed by the time it reaches the wheels, and the car may move backward, or the transmission to the wheels may be thrown out entirely and the motor revolve idly while the car is at rest.

All this is at the driver's command and levers at his side enable him to change the gears or set the brakes. A foot pedal provides for connection between the engine and the transmission gearing, while another pedal and a knob or lever at the steering wheel control the admission of gas. Then another knob or lever at the wheel regulates the electric spark exploding the mixture in the cylinders. For gasoline is not sufficient and electricity must be called to our aid, and the electrical side of the motor car is hardly less important than that dealing with the explosive vapor. It is an electric spark that fires the charge in the cylinders, it is electricity that in many cars is called upon to start the engine and to light the lamps, so that we are now independent of muscular effort in cranking the engine and of matches that go out in a gust of wind.

The spark may be produced by an induction coil supplied from a number of dry cells similar to those used for ringing electric bells or from a storage battery that is charged at some garage or electric station. But it is not necessary to use batteries, for once the crankshaft is in revolution we are able to produce current mechanically, and for that purpose what is known as a magneto or generator is employed. Once the crankshaft is set in revolution the magneto or generator will revolve rapidly and the battery and induction coil needed perhaps to start the engine may be cut out and the machine operated continuously.

With the auspicious beginning of the application of the steam-engine to road locomotion in Great Britain in the first thirty years of the nineteenth century, it would have been supposed that steam would have become a favorite form of power as soon as the need for automobile vehicles was established. The great objection, of course, to steam was the weight of the engine and boiler with its fuel necessary to generate a certain amount of power. In fact, it was not until liquid fuel became generally available that attempts were made to build light vehicles in which steam was employed. With the invention, however, of the flash boiler in which a limited amount of water was quickly turned into steam, Leon Serpollet in 1888 used such a boiler and engine to propel a light tricycle, and light steam cars were developed which enjoyed a brief and temporary vogue. In 1895 a steam omnibus in a road race from Paris to Bordeaux covered 745 miles in 90 hours and 3 minutes. Steam cars and trucks possessed a number of advantages, for the steam-engine has a wide range of power and is susceptible of easy control through the simplest of mechanisms. Such an engine is quiet in operation, works with a minimum of vibration, and can be easily started or re-started after a temporary stop. Its chief disadvantages are the time required to produce steam after the water in the boiler has been allowed to cool, and the attention that must be paid to the various gauges and indicators showing the amount or pressure of water, steam, etc.

For a number of years the steam-driven motor car had all but disappeared, as the gasoline motor for most purposes was found to be more convenient and efficient. But in 1917 a new form of steam car was brought out which involved many radical departures from previous practice. The inventor retained the radiator of the gasoline car with its large condensing surface, so that he was able to condense all the steam and with one filling of the water tank drive some 1,500 miles. The carbureter also was retained, and a spark plug was used for ignition, so that in less than two minutes with cold water steam could be generated.

The water carried the lubricating oil which prevented the formation of scale in the boiler and secured the continuous and automatic lubrication of the cylinders.

The type of engine used was a simple una-flow double action, 2-cylinder locomotive type of steam engine with slide valves on top of the cylinders, which are arranged horizontally. It is possible to reverse the engine directly without any intermediate device, and the power is transmitted to the rear axle by means of two spur gears. There are no change speed gears and no clutch, and the entire control is through the throttle valve. The boiler is of the water tube type, formed of a number of sections each of which consist of two horizontal headers connected by 16 vertical tubes. The headers and tubes are welded by the oxy-acetylene process. The water level is maintained automatically and the steam in the upper part of the tubes becomes superheated. Once the fuel is ignited the operation of the combustion is automatic, and a small blower, electrically operated, supplies the necessary air through the carbureter into the combustion chamber. Of course with the steam car the absence of any gear shifting or spark control makes it remarkably convenient, and it is able to start at once from a position of rest even on a considerable grade without the agency of any gears found in a gasoline car.

The storage battery with its many improvements has been extensively utilized on many forms of vehicles. Its advantages and its disadvantages are obvious. The radius of activity is of course limited, though ever increasing, and the driver absolutely depends upon his charge or the proximity of a charging station in arranging his journeys. The battery is apt to deteriorate rapidly, especially with careless use, and the expense of renewals is comparatively large. On the other hand the arrangement of motors is very simple, the problems of adjustment and lubrication are reduced to a minimum, the training of chauffeurs is much simpler, and under certain conditions of maintenance substantial economies may be secured. Thus where isolated

plants are maintained there are certain times of the day when the load is smaller than economy of operation warrants and at these times storage batteries may be charged at small cost. It is, however, the simplicity of the arrangement that commends itself, and for urban use on level roads graceful phaetons driven by ladies are especially useful, while for certain commercial purposes heavy trucks, where speed is not an essential item, can be handled with considerable economy.

The advantages of the electric car, including its cleanliness and its freedom from fire risk and odor, permit of its ready storage without a special garage, while on the road its ease of control is much appreciated. It is available either in cold or warm weather, and the new Edison battery and improved forms of lead battery give greater durability and economy so that its radius of action is increased and its mileage lengthened. Better transmission mechanism and axles, including roller bearings and silent chains, and more efficient motors also have contributed to its development, while the light weight of batteries and machinery have made possible bodies graceful in design and comfortable for the passengers.

The electric supply companies have also contributed to the increasing popularity of the electric vehicle by increasing the number of supply stations, making special rates for charging at certain times, and for the installation of rectifiers whereby an alternating current may be transformed into a direct current at the garage of the customer.

In war the mechanically propelled vehicle has in large measure deposed the horse and has become essential to armies in the field. Where there is need for the rapid transport of infantry to any desired point on the line, or the rapid movement of heavy guns to an effective position, the motor must be used. Thus when the Germans made their advance on Paris, many city omnibuses were pressed into service to carry the French and English soldiers to the firing line. Where regular or military railways would not serve, various forms of motor vehicle were used for many

purposes, and generals and staff officers constantly employed automobiles driven by men who had been racing drivers in their rapid visits along the lines, and for conferences with distant corps.

In the transport of the wounded from the field of battle to the nearest base or hospital, the motor vehicle played a distinct and valuable part, and much suffering and loss of life was prevented by the prompt attention which the ambulances with their volunteer drivers were able to render. Light American cars organized into sections and driven by American volunteers made for themselves a unique record for efficiency and humanity. Ambulance bodies mounted on the standard chassis of popular low-priced American automobiles more than rivaled in efficiency the heavier vehicles of the continental and British armies. So light was the American car that it readily could be replaced on the road when it was ditched without any other agency than the strong arms of nearby soldiers, and so interchangeable were its parts, that in case of breakdown a telephone call for the emergency car would bring extra parts with a mechanic who speedily could effect the repairs on the spot.

Such in outline is the mechanical vehicle as now used for pleasure, business, and in war. Its efficiency has increased as its use has extended and it has worked many changes in modes of life and in commercial activity. It is a triumph of the mechanical age, but it brings us closer to nature and prevents the abuse and suffering of animals. By it we are able to live more efficiently and broadly, to utilize the suburbs for our dwellings in place of crowded cities, to conquer new worlds, and to gain health and stimulating recreation mid the green fields of the country.

MODES OF TRAVELING

The Flying Machine

By HERBERT T. WADE

THE conquest of the air for ages has been one of the ambitions and ideals of man, and the possibility of flight high above the earth long has been cherished as a mechanical achievement of no mean degree of merit. In the early days of Greek mythology we find the familiar tale of Dædalus and his son, Icarus, flying on wings of wax, and like many a modern aviator meeting with disaster because they failed to take into consideration the strength and properties of their materials of construction, for flying too near the sun their wings were melted by its heat and they were hurled headlong. Another legend, also from antiquity, tells us how the Greek mathematician, Archytas, sought to reproduce the flight of birds with a mechanical device, where hidden and enclosed mechanism was able to send on its journey a wooden dove.

Thus we see that the ambition and ideas of the ancients as regards mechanical flight and the exploration of the air were scarcely different from those of modern inventors. Nature indeed had set a hard task, for so completely and efficiently had the problems of aërial dynamics been worked out in the case of the animal world that any attempts to realize the same result mechanically for centuries were fraught with failure and disappointment. Indeed it was apparently so impossible of attainment, that even in the recollection of most of us the names of would-be inventors of flying machines were classed in much the same category as those seeking to accom-

plish perpetual motion or other physical impossibilities. Therefore it is interesting to realize that with the persistence of this idea and ambition through centuries, it has been only in our own day that the full realization has taken place, and it is hardly too sanguine an expectation to look forward to the time in the near future when air locomotion, if not as general as travel on the surface of the earth, may be accomplished with as great facility.

With the example of the birds, it was but natural that the earliest and most persistent attempts at the conquest of the air should be made through mechanical devices which aimed to reproduce their action, but with the growth of the science of chemistry and the realization of the properties of gases lighter than air, a promising field was opened which resulted in the discovery of the balloon which for a number of years met with greater practical success than devices where flight was attempted by mechanical means.

Accordingly this has resulted in two great divisions of devices for aërial navigation. First, those designed for mechanical flight, or the air-soarers, machines heavier than air that in the main go back to the bird as the natural model, and by various contrivances of wings and screw propellers seek to control the direction of flight; and second, the air-ships or balloons where bags or envelopes of light fabric containing large volumes of gas, lighter of course, than the displaced air, float either at will or by various mechanical means, such as propellers, auxiliary planes, and wings, are controlled as to their direction.

The discovery of hydrogen and the realization of the fact that air when heated expanded and was less dense than at lower temperatures led to the invention of the hot-air and hydrogen balloons that amused and interested the French Court toward the end of the eighteenth century. Successful experiments with balloons of larger size soon led to their use to carry aloft one or more passengers, and while these spherical balloons were more or less at the mercy of atmospheric currents and would be carried in whatever direction the wind chanced to blow, they aroused an interest that has never

ceased, for every year international competitions of non-dirigible balloons or *aërostats* for the James Gordon Bennett Cup are held either in Europe or in America. Many a tragic story could be told of the wonderful ascents and voyages made by the intrepid *aéronauts* seeking meteorological data, or such exploration as *Andrée's* ill-fated trip toward the North Pole, of which no trace ever was found.

Although the *aërostat*, or spherical balloon, can hardly be considered as a flying machine, yet it is capable of extensive voyages and on March 24, 1912, a record trip of 1,492 miles from Paris, France, to near Kharkov, Russia, was made, and frequently trips over 1,000 miles have been recorded in the races for the Bennett Cup, and altitudes of over five miles by meteorological observers have been made. Such voyages, interesting and thrilling as they may prove, do not permit of adequate means of control as regards the direction. Therefore Professor Charles, one of the scientists who early exhibited before the French Court, sought to realize this in a melon-shaped balloon resembling a boat, which could be propelled by six silk-covered oars and guided by a silk rudder. Other inventors attempted to apply manual labor and gradually a torpedo- or cigar-shaped body was evolved where spring power, electric batteries, and other forms of energy were used with more or less success. But it was not until the application of the internal combustion or gasoline motor that the dirigible balloon was put on a practical basis. By securing adequate power with light weight it was possible to drive a balloon of elongated shape in the face of a moderate breeze, and Santos-Dumont, beginning in 1898, made a series of such dirigibles, or small air-ships, in which he was able to navigate above the city of Paris.

His success and that of other inventors, due in part to the improvement of gasoline motors, led to the design of even greater air-ships and Count Zeppelin began his work which resulted in a series that by 1913 had reached the twentieth. Various forms of steering and adjusting planes were employed and the balloon itself was made in a series of cells on a rigid framework of considerable strength. In this way

it was distinguished from air-ships that were either non-rigid or semi-rigid, and which were used with greater or less success in the various military services.

The large air-ships of Count Zeppelin early were put to commercial service, making voyages about Germany, and tickets were sold just as for regular railway trips. The American traveler could purchase such a ticket at the office of the steamship and tourist agencies in New York, paying in 1912 or 1913, fifty dollars for this privilege, and after reaching Germany and presenting it at the home station of the air-ships, at Friedrichshafen, he could enjoy an aerial trip of several hundred miles to some other German city.

But the air-ship is hardly a flying machine despite its engines and propellers and the fact that various inventors and designers have attempted to cross the Atlantic Ocean or have essayed to reach the North Pole and other unexplored regions of the earth. It is a device for floating through the air rather than the vigorous flight of the bird with its muscular energy. Accordingly we think of flying machines as devices heavier than the air they displace, not much lighter, as are the gas-bags of both the spherical balloon and the air-ship with its stabilizing planes and propellers. We must consider not merely floating in the air, but how a body or surface that is much heavier can be supported. We have seen a bird maintain itself in the air simply by the spread and poise of its wings without apparently making the slightest exertion, and we have seen a kite borne high above the earth by the effect of the pressure of wind against its surface, the latter being inclined at a slight angle to the direction of the wind. Now the wind blows against the kite which is restrained by the line connecting it with the earth, but if we were to push the kite forward at the same angle of inclination and against stationary air, we would have the same effect as if the wind was blowing against it.

This, then, is the simple principle of the *aéroplane*, notwithstanding vast amounts of mathematical reasoning and mechanical experimentation to secure its practical realization. In this development American scientists and inventors have

played a conspicuous part, and no one has done more to make possible the evolution of a successful flying machine and to place the science of *aërodynamics* on a firm basis than Professor S. P. Langley, who was the secretary of the Smithsonian Institution at Washington. Even before opportunity was given him for experiments on a large scale, under the auspices of the National government, he had made investigations as to the possibility of supporting weights in the air through the agency of planes; and numerous models were built by him which seemed to indicate the truth of his theory and reasoning.

Langley's large sized models were eminently successful and eventually a machine sufficiently large to carry a man was successfully built and failed on its trial trip only on account of an unforeseen accident not involving any basic principle of design or construction. Unfortunately Langley's experiments at the time failed to receive the popular and official support they deserved, but after his death and the publication of his various memoirs dealing with his work, their value was universally acclaimed and it was found that the most successful monoplanes used in rapid and long distance flight carried out his ideas and proved beyond the slightest question the entire practicability of his designs and methods.

In addition to Langley's work Otto Lilienthal, an Austrian mechanical engineer, had studied the problem of bird flight and with confidence in his ideas he built himself pinions like those of the hawk and buzzard. In 1891 he began to glide through the air by precipitating himself from heights in the face of a strong wind and trusting to his wings to bear him in a soaring or gliding flight over a considerable distance, sometimes as far as one-fifth of a mile. In August, 1896, he was killed by a fall due to the failure of his light wings in a sudden gust of wind; and the same fate also befell an Englishman, Colonel Percy S. Pilcher, who, working along the same lines, met his death in a similar accident.

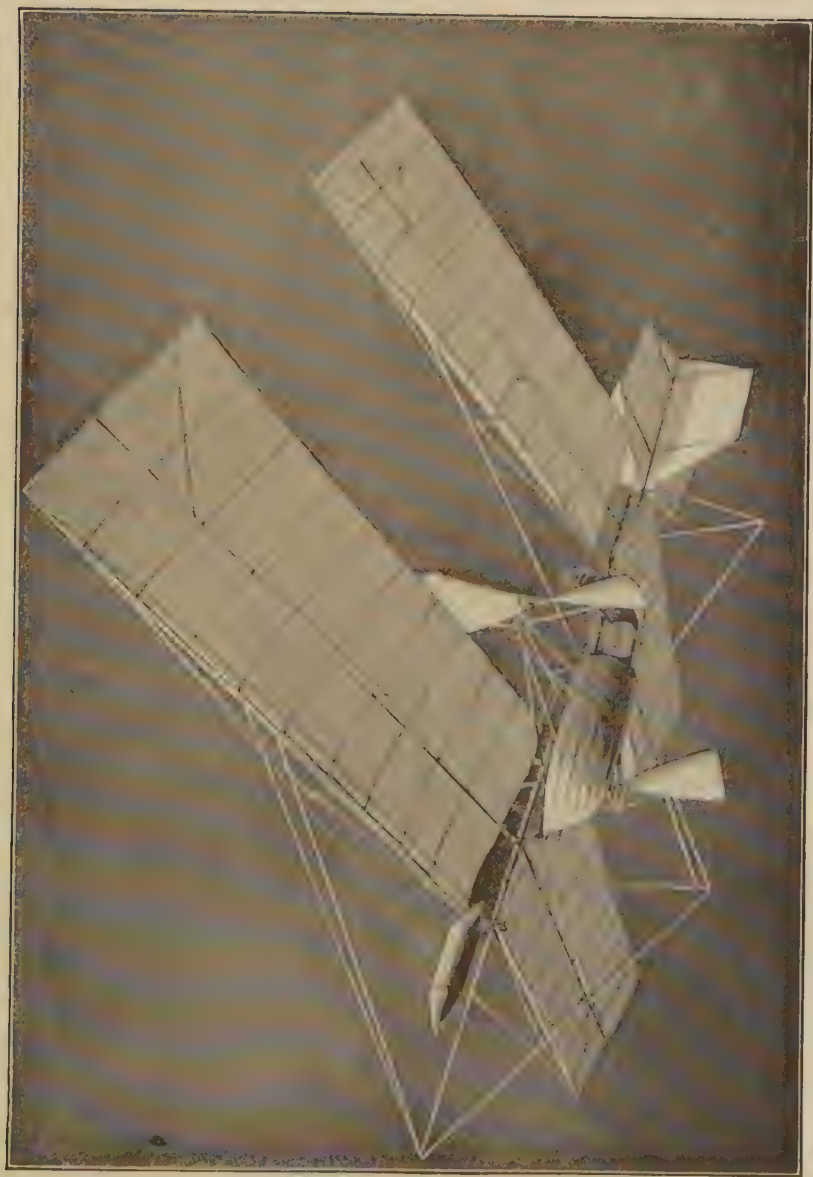
Better fortune attended the experiments of Octave Chanute, an American engineer, who devised improved gliding-machines, and tried them out on the shores of Lake Michigan. He experimented with machines of as many as five planes or

"wings," and, furthermore, he hit upon a great improvement by making flexible the tips of the wings, which thus bent backward under sudden gusts of wind, and in doing so largely counterbalanced the travel of center of pressure. Another innovation resulted when A. M. Herring, then assisting Chanute, suggested the movable tail instead of the rigid one hitherto used. While these encouraging trials, begun in 1896, were taking place, men in various parts of the world followed the fascinating task of solving the flight problem. Alexander Graham Bell, in America, conducted experiments with his tetrahedral *aéroplane*, and Sir Hiram Maxim, in England, constructed a gigantic *aéroplane*, weighing 8,000 pounds, with engine, wings, and propellers, which he really raised by its own power, proved its speed, but failed to gain any control in balancing or in steering.

In the meantime in the United States two ingenious inventors in Ohio had been quietly experimenting with the problems of flight. To Wilbur and Orville Wright may be given the credit for the first practical heavier-than-air flying machine. Skilled as mechanics, they were devoting themselves also to theoretical considerations and obtaining the advice and assistance of those best qualified to aid them. In 1900 they began out-of-door experiments with a new form of gliding machine. While Langley and others had used wings set at a dihedral angle—that is slanting upward from the center where they joined—the Wrights pinned their faith to a pair of long, rectangular, superimposed planes, or wings, which were connected by vertical posts and braced with wires. These wings were also curved downward at the tip.

Instead of the arduous method pursued by Lilienthal and Chanute, who had to climb some height each time they wished to soar, the Wrights chose an arena of North Carolina sand-dunes near the Atlantic coast where the winds were strong. Here, during the summers of 1900-02, they mastered the art of gliding, their machines undergoing many alterations of plane curving, surface support, and rudder and sail formation.

In the summer of 1902, between 700 and 1,000 glides were made, the longest being 622 feet. A gasoline-engine was added



LANGLEY'S AERODROME

to the glider in 1903, thus making of it a self-propelled flying-machine, and the successful inventors started upon their larger navigation of the air. On December 17 of that year four flights were made in an *aéroplane* weighing 745 pounds, with a 240-pound motor, and the longest trip covered a distance of 852 feet. Improvements followed rapidly, increasing the length of the experimental flights. Equilibrium, however, was still an elusive quantity, and the difficulty of turning seemed insurmountable. During 1905 many radical changes were made in the *aéroplane*, and in the month of September the trouble in turning came under control of the persistent inventors. From September 26 to October 5 six flights, averaging 15 miles each, were accomplished, and on the latter date a flight of 24 miles was made in 38 minutes. As these trials were always on a curved course, the straight-away speed was estimated at 40 miles an hour.

Up to this point the Wrights had worked in secret, but having sufficiently mastered their mechanical and *aërial* problems, they now made public their wonderful achievement. Beginning with the autumn of 1908, Wilbur Wright in France, and Orville Wright in the United States attracted the attention of all the world to their brilliant flying performances. On September 9, at Fort Myer, Virginia, Orville flew for 57 minutes and 31 seconds at 38 miles an hour; three days later he remained continuously in flight for 1 hour and 14 minutes, attaining occasionally a speed of 50 miles an hour. Wilbur, however, at Le Mans, France, more than met the expectations he had aroused. On September 21, he made a continuous flight of over an hour and a half, and in the last day of that year (1908) he remained aloft for 2 hours 9 minutes and 33 seconds, flying 76½ miles. During the summer of 1909 the many aviators who had taken up the *aéroplane* broke a number of former records, noteworthy among them being Blériot, who, on July 25, flew across the English Channel.

The Blériot machine was notable as marking the development of a satisfactory monoplane with a single supporting surface instead of the two planes in the machines of Wright, Curtiss, and other aviators. With it the resemblance to the

bird was more complete, and one is able to trace many points of similarity in the monoplane of Blériot and his successors with that designed by Professor Langley and considered suitable for mechanical flight. In the shape of the body and its smooth covering this resemblance to the bird was carried somewhat further by later inventors, and the propellers which originally had been placed behind were now located at the front of the *aéroplane*.

As soon as successful *aéroplanes* were found possible, a large number of inventors devoted themselves to their design and construction and many modifications were made from the types originally evolved. Many of these proved defective and a large number of accidents were due to inherent weakness, lack of mechanical strength, and faulty construction. But in the meantime the aviators themselves, nothing daunted, practised assiduously with machines turned over to them by the makers, and added various devices and improvements of their own. As a result mechanical flight became very general and in competition and practice the distances and periods were greatly extended. Machines of high speed, mostly of the monoplane design, were developed, while the biplanes of the Wrights, undergoing continual improvement, were found to possess great power and stability.

Soon the design and construction of *aéroplanes* and *aéroplane* motors developed into a special branch of engineering and many types of planes and engines were evolved. Considerable experimental work was done, and the governments of Europe realizing the availability of aircraft for their great armies undertook the systematic organization of *aéro* squadrons and the training of aviators. Once the novelty had passed, it was the military application of the *aéroplane* that established its manufacture on a commercial basis. Only the more enthusiastic claimed that the *aéroplane* soon would develop a commercial use for the transportation of mails and small parcels or passengers. Nevertheless various mail routes were proposed and from time to time the United States Government indicated that

it would entertain bids for aërial transportation of mail over sparsely settled country.

After the outbreak of the great war the development of the aëroplane followed in connection with its military application, for it was apparent that it had completely changed the art of war. Where aëroplanes had been counted by the tens, by the second year of the war they were numbered by the thousands, and the mastery of the air was a large and vital essential. Speed early became a desirable element, because the quick-flying observer making a reconnaissance over or beyond the enemies' lines was anxious to return with his information as soon as possible and to escape from the hostile planes that would be sent out after him. Reliability of the motor was another consideration, for failure of the engine, always a serious matter, became doubly so when the aviator was forced to descend in hostile territory and together with his plane be captured by the enemy. Power to carry aloft a considerable weight was a further desideratum, inasmuch as it conditioned the amount of fuel, the number of observers, and the amount of high explosives that could be used for bombing.

As a result of these needs there came to be developed various classes of aëroplanes, all of more or less efficiency but at the same time intended for very different work. These developments naturally affected the design of the aëroplane regarded simply as a machine and with a view toward its eventual application in the arts of peace. The high-speed aëroplane would serve as a type for mail service, while those of greater lifting capacity would be employed in the transportation of mail or express packages, and the largest machines for the transport of passengers or transoceanic voyages. Furthermore the war encouraged the development of automatic control devices, for it was essential to have skilled aviators, and with such improvements it was no longer a matter involving particular aptitude and long periods of training.

An important development of the aëroplane that was soon to be taken advantage of on the outbreak of the war by

the belligerent forces was the hydro-aëroplane which could arise and descend on the surface of the water. Instead of the familiar rubber-tired wheels there was a boat construction to its hull so that it could descend and rest on the surface of the water and could ride out heavy seas. As early as 1913 hydro-aëroplanes had been developed, which, tested on the rough waters of the Mediterranean, it was found could rise in the teeth of quite a strong gale. Just as the armies of Europe had called for aëroplanes on the outbreak of the war, so hydro-aëroplanes were in great demand, particularly to combat the submarine when its ravages became serious. These hydro-aëroplanes in addition to convoying numerous ships also had their share of actual battles, and their heavy armament at times was vigorously employed against torpedo boats and submarine bases as well as in battles with enemy aircraft.

The successful aëroplane was indeed a triumph of mechanical engineering. It was not until the internal combustion motor or gasoline engine had been developed for the automobile and similar machinery that adequate power with minimum weight was available for the needs of the aëroplane. With a suitable engine evolved, designers were soon able to construct efficient planes, bodies, and propellers that constantly showed advance over previous practice and were available for the new needs of service. When we recall that in 1917 a call went up for one hundred thousand aëroplanes for the Allied armies and that it was urged the war must be won in the air, it is possible to realize how much aviation has contributed to the progress of the world. In 1903 was recorded the first practical flight of a self-propelled flying machine heavier than the displaced air. By 1917 the western front of Europe was occupied by flying legions, and the history of the world's civilization was being largely affected by the device of two American inventors. It has taken war to develop aëroplanes of high efficiency and safety, to evolve machines that are mechanical triumphs yet are available also for peaceful application, and the advancement of civilization.



AN U. S. ARMY HYDROPLANE.

MODES OF TRAVELING

The Gyroscope and Its Applications

By HERBERT T. WADE

THE simple spinning lead disk in a ring frame suspended from a string or balanced upon a small pedestal is a favorite toy of the shops and street venders, and its calm and easy motion around its supporting string or point at once arouses our interest. It is an illustration of that famous law of motion enunciated by Sir Isaac Newton in which he stated that every body perseveres in its state of rest or of moving uniformly in a straight line, except in so far as it is made to change that state by external forces.

In our elementary gyroscope, as this toy really is, we have a disk capable of being set in motion around a central axis. The more rapid the rotation of the disk the greater the force acting on it tending to force its particles away from the center. Now this force not only produces a steady rotary motion, but a motion in one plane or a series of parallel planes if we consider the individual particles making up the disk, which must be understood as having its entire mass concentrated at the extremity of the radius of rotation, as in fact is secured by having a heavy rim in the case of the disk or fly-wheel. In the spinning top of the boy we have the disk in the upper part and its center in a vertical line passing through the point, and as the upper part revolves its motion being in a horizontal plane is sufficient to overcome any preponderating force of gravity in a single direction tending to throw it out of balance. It is not necessary that the top should spin in a strictly vertical position, in fact this often occurs, and we might so arrange it that its axis of rotation was oblique or even horizontal, provided that due support was

given. Thus when we have a horizontal axis duly supported at one end we have the simple gyroscope top of the toy shop where the inverted cone has been flattened to a symmetrical disk.

Just as the top stands upright so long as its motion lasts, so the spinning disk will maintain its original plane of rotation and any force that acts to displace it must either act to destroy the rotation or to produce a complexity of motion resulting in a spiral motion of the axis in general in a direction at right angles to the force acting. But by speeding up the rotation of the disk its momentum or amount of motion in the original plane may be made a very large quantity so that it will not only resist opposing forces but will maintain its direction of motion despite many and varying forces. Thus it early occurred to the gunsmith to rifle his barrels and using an elongated projectile give it a rapid rotation around a longitudinal axis when it left the gun. In this way the projectile is maintained in proper and constant position throughout its flight and the nose of the bullet strikes the target first as it should.

After the gyroscope came to be designed as an instrument for physical investigation by Bohnenberger, a German mathematician who flourished in the early part of the 19th century, as its mathematical properties were studied and understood, the value of a rotating disk for maintaining a position of steady direction became more generally to be realized, and its use was suggested for various purposes. Thus in 1852 Foucault, a famous French scientist, who had been demonstrating the rotation of the earth by means of a long pendulum in the Pantheon at Paris, proved the same phenomenon by means of a gyroscope, where a comparatively heavy disk was so mounted on universal joints or gimbals, like a ship's compass, that it was free to move in any direction around an axis of rotation or gyration. Now when this disk is caused to rotate rapidly and is pointed at some fixed point, as a star for example, if the earth were stationary the direction would be maintained, but as the earth moves the direction of the star constantly changes, so that while it is fixed in space it has to the observer on the earth an apparent motion. Yet the axis of the rotating gyroscope still points in its original



THE GYROSCOPE.

direction, and by using a microscope to determine the difference in position of the axis of the gyroscope with respect to a fixed direction on the earth, Foucault was able to demonstrate and compute the rate of motion of the earth as he had done with his long pendulum.

From such peaceful applications of this important principle, it is quite a transition to the torpedo now used in naval warfare with such deadly success as was shown in the Russo-Japanese war. The torpedo is forced from the discharge tube by the explosion of a small quantity of powder, and on reaching the water its motion is produced by compressed air engines driving propellers. Of course there will be many forces acting to change the direction of the torpedo after its discharge from the tube in the desired direction, but the idea early occurred to an American naval officer, Commander Howell, U. S. N., that if a gyroscope could be introduced to control the steering gear this largely would be obviated so that a straight journey along its path of destruction might be followed.

This idea was also developed by Lieutenant Obry of the Austrian Navy, whose mechanism finally was universally adopted, and the Obry gear is today familiar in the torpedoes of all navies. As used it is simply a heavy fly-wheel or gyroscope rapidly rotating under the influence of a powerful coiled spring and mounted with its axis fore-and-aft and in connection with the rudders. The axis of the gyroscope at the time of the torpedo's discharge points directly at the target and so long as the torpedo follows this direction there is no active effect. But if anything causes a deflection or change of direction then the axis of the gyroscope is at an angle to the direction of the torpedo and develops a force which acts upon the steering mechanism to restore it to the original direction. In other words, the gyroscope here, as in the top or the scientific instrument, resists any force tending to displace the axis of rotation and by acting on the steering devices restores the torpedo to the original direction.

But if its function is to destroy it is also to save, for the naval engineer has applied the gyroscope to his compass and found a device that is of great value in checking its indications. This consists of a gyroscope with horizontal axis mounted on gimbals

and free to move in any direction. Its wheel can be kept in rapid rotation by an electric current from primary or secondary cells or from the lighting circuit of the ship. Now in many cases the iron of the ship and other causes affect a ship's compass and adjustments of the most refined character are necessary which may be changed completely by various circumstances, such as change in cargo, magnetic storms, etc. With the gyroscope compass it is possible to determine the direction of the true north either by the bearing of two shore marks determined with high precision, or by means of the magnetic compass itself when working under favorable conditions. Such compasses now are widely used and are found on the battle-ships of the United States Navy and on many of the larger and newer transatlantic liners.

The control of the compass, however, is a matter that directly concerns the navigator, but when it comes to the pitching and rolling everyone is interested, and the passenger troubled with seasickness will turn at once to any new device that will lessen the motion. Now once again the gyroscope has been applied, this time to prevent that rolling. With that enthusiasm to harness science to the service of man so characteristic of the Germans, Dr. Otto Schlick, an engineer, made a series of calculations and experiments that demonstrated to his mind that here was a chance to eliminate this rolling, cut down the amount of vibration, and in short make sea travel in rough weather not only safer but pleasanter by using a gyroscope.

After computing the dimensions of a gyroscope sufficient in power to accomplish the desired results, Dr. Schlick experimented with a German torpedo boat the "Seebaer" which was 116 feet in length and of some 50 tons displacement. He mounted his gyroscope on a vertical shaft which could revolve in bearings formed in an enclosed casing which was mounted on two trunnions. These in turn were attached to the structural framing of the vessel. In other words, the shaft or spindle is capable of moving in a fore-and-aft direction and the plane of the gyroscope disk ordinarily is horizontal. The disk is also a steam turbine, steam being introduced and exhausted through

the trunnions. In this way a high velocity of revolution can be communicated to the disk, while brakes are arranged to control the movement of the iron casing of the machinery. Just as soon as there is a tendency for the vessel to roll, the motion is communicated to the gyroscope and the horizontal disk rapidly rotating resists any attempt to move it out of its original plane. Instead there is a tendency for the axis of the gyroscope to move in a fore-and-aft direction, but this can be controlled by the brakes and the energy communicated to the gyroscope by the waves is transformed into heat. So we have the rolling motion of the ship transformed into motion in a vertical plane in the direction of the axis of the ship which can be controlled by means of band brakes.

The success of the invention, especially on moderate sized vessels, would seem to afford a wide field of usefulness, as there are many rough trips where small vessels are used. For example, the voyage from New York to the winter resort, Bermuda, accomplished in small or medium sized vessels, often is marked by heavy seas. Now if a gyroscope could be used to reduce the motion on these vessels, it would obviate the necessity of employing larger and more expensive ships. Furthermore if a war vessel could be stabilized, more accurate gun fire would be feasible. Experiments have shown the practicability of using the gyroscope to prevent rolling on large vessels, and to produce such motion on steamers used as ice breakers or in navigating ice-filled harbors.

The stabilizing of a ship naturally suggested a system of control for an *aéroplane* which might act automatically and relieve the pilot from incessant attention to changes of position and atmospheric conditions. Accordingly, Mr. Elmer A. Sperry, who had devised the gyro-compass, together with his son Lawrence B. Sperry, conceived the idea of using a gyroscopic device to stabilize the *aéroplane*. With rapidly revolving gyroscopes any change of the plane with respect to its determined position would develop an opposing force sufficient to operate control valves acting

by compressed air on the various rudders. Thus when there was a tendency for the *aëroplane* to tip about the horizontal axis, the longitudinal stabilizer would be brought into operation and the horizontal rudders would act to restore the machine to the normal position. In addition to the longitudinal stabilizer, the equipment consists also of a lateral stabilizer with its own gyroscope which produces the valve control of the ailerons or wings at the extremities of the supporting planes, and prevents lateral tipping.

This invention shown in France in 1914 before the great war was developed into a special automatic pilot especially for military purposes, which freed the aviator from the necessity of having an observer, as the pilot could drop bombs, make observations, take photographs, and so forth.

Quite picturesquely the *aëroplane's* automatic pilot has been compared in its three functions to the heart, the brain, and the muscles of the human pilot. The gyro units correspond to the brain, the generator with its electrical mechanism to the heart, while the servo motors operating the valves are likened to the muscles that move to counteract even the slightest tip. Naturally this gyroscopic device figured prominently and became an essential element of military *aëroplane* equipment.

But the end of the application of the gyroscope has not been reached. On land the problem of the single rail for the rapid transit of passengers and of small freight has always been an attractive one to inventors, and the problem of balancing the car so supported by various forms of bearing and guide wheels has figured in numerous inventions. In England some years ago an inventor named Brennan constructed a monorail line on which cars fitted with two gyroscopes revolving in opposite directions were used. The preliminary experiments promised considerable success and many of the details were satisfactorily worked out.

The gyroscope shows the tendency of modern invention to take some abstruse idea that physicists have evolved and mastered, and then to find an important use that will be of great benefit to mankind.

CONVEYANCE OF THOUGHT

The Wireless Telephone

By HERBERT T. WADE

WITH the telephone a commonplace essential of our daily life and with wireless telegraphy developed to the point of commercial transatlantic communication, it is not unreasonable for the average man who has firm faith that eventually electricity will accomplish everything in the way of communication or transportation, to ask where is the wireless telephone. He knows that the telephone he can handle without any special training or knowledge, and with hardly a thought communicate instantaneously and privately over such distances as between New York and Omaha; and it seems to him equally fair to demand that he should be able to call up the "Lusitania" in mid-Atlantic and talk directly with some relative or business associate.

But our friend is really not altogether reasonable, for he fails to recall that telegraphy was long established on a good working basis before the telephone was a realized success and perhaps he needs to be reminded of the fact that the transatlantic dispatch of news telegrams by wireless followed some ten years after Marconi's fundamental invention of 1897. Well, we must counsel patience to our business friend and tell him what, perhaps he does not know, that wireless telephony early occurred to scientists working on the application of the ether waves and that a number of clever investigators have long been experimenting in this field, so that to-day wireless telephony is not only a possibility but an accomplished fact and its wide extension and use is more and more approaching realization. Difficulties have been and are enormous, but little by little they have yielded, and

while to-day we may look at wireless telephony as a scientific fact, its general use is a promise of the near future.

It is only a few years since aerial wires on large hotels and office buildings indicated that here messages were being sent and directly received. Once the queer spider web structure to be seen around a lofty flag pole or mast at army posts or navy yards, seemed strange, and the fact that ocean going steamships were equipped with arrangements of wires suspended from the rigging to intercept the waves passing through space was unusual. To-morrow we may see these or similar arrangements of aerial wires even on the roofs of our city dwellings or carried from the flag pole on the lawn, and without the services of a trained operator, simply by taking down our telephone receiver, we may listen to voices at sea or perhaps to the music from a concert or opera transmitted through space just as it is sung on the great stage. Perhaps we shall employ that indispensable friend, the ordinary telephone, and ask to be connected to the wireless station where our message may be automatically relayed outward over the ocean to the swift greyhound of the sea rapidly plowing her way through the waves. Here the ship's operator catches the call signal, learns whom we wish to talk with and in a cabin below a call bell tinkles and we are in communication with our friend, just as if we were talking between Philadelphia and New York. Of the future perhaps, but not so long a future, if we consider what has been already accomplished. But let us bear in mind that as now we see it, wireless telephony does not mean the scrapping of our present efficient system of wire lines any more than the cable and the aerial copper and iron conductors have been supplanted by wireless telegraphy, but rather that the range and method of transmission of the human voice will be widened and improved.

At the beginning we have to understand the fundamental fact, or difficulty we might term it, in all telephony both with and without wires, and that is the nature of speech. The human voice causes vibrations in the air, and in fact it is the rapidity, and the nature of these vibrations that distinguishes one sound from another and make possible the expression of intelligible ideas. Now all sound, whether it be music, a discordant

noise, or human speech consists of these vibrations and they are characterized by extreme rapidity. These rapid vibrations must be handled in some way that they may be reproduced at a distance. In the case of our ordinary telephone, the vibration of a diaphragm under the influence of the voice alters the electrical resistance of granules of carbon in the nickel case of the transmitter, so that variations will be produced in an electric circuit of which a small battery is a part. And these variations in the intensity of the current will cause an iron diaphragm in front of an electromagnet in the receiver to vibrate in unison and thus reproduce the sound. Now can the electromagnetic waves from an aerial wire that pass over the world at high speed be so controlled that they too can be put in unison with the sound waves in the air, and either be interrupted at sufficient speed or so varied that the ever changing vibration of the air waves set into motion by the voice could be reproduced? That is the problem of wireless telephony.

These electric waves used in wireless telegraphy are produced by the rapid oscillation of an electric current in an aerial wire from which the waves are sent out in all directions. When these waves encounter a similar aerial wire they affect the electrical conductivity of some device used in the circuit as a detector. For wireless telegraphy the problem is simply to produce electric waves of the desired frequency and form, and then interrupt their production in accordance with the Morse or some other determined code of telegraph signals. By using a telegraph key to make and break the circuit the sending out of the waves is regulated.

Telegraph signals sent by hand do not involve any great rapidity as compared with the signals that would be required to reproduce sound vibrations, for here there are thousands of vibrations which would require corresponding changes in the circuit. Now with the electric waves first used for wireless telegraphy a wave was generated where at first the vibration or movement of the ether was considerable but which soon rapidly died down. In other words it was a damped vibration which sufficed for telegraphy as long as it traversed the necessary distance, but such a wave was not found at all suitable for telephony.

But as the physicists studied the waves by adjusting their circuits and their sources of current they found it was possible to produce waves which proceeded with a regular degree of vibration, not intense at first and gradually dying out, but representing as they progressed almost the same degree of motion, in other words, undamped waves. Once this was realized it was possible to find a means for varying not the frequency or even interrupting the waves but to change their amplitude. To pass now from theory to experiment. There are two methods of producing the undamped vibrations. The first employs an arc where the electric spark is maintained between the carbon rods. If from either side of this arc conductors are led and a satisfactory circuit arranged with what the electrician terms capacity and inductance, we have very rapid oscillation set up in the circuit and electric waves sent out from an aerial wire in the form of undamped vibrations of the ether.

Thus it was found by Valdemar Poulsen that if the arc formed between carbon and copper was maintained in an atmosphere of hydrogen, or a hydro-carbon gas or vapor, and between the poles of a strong electromagneto, that undamped oscillations could be produced ranging as high as 500,000 or more. Poulsen found this device very useful both in wireless telegraphy and telephony and with his modification and improvements has achieved remarkable success in long distance work.

In the United States, de Forest, who has developed an effective and practical system of wireless telephony also uses an arc which at first he placed in an atmosphere produced by a burning alcohol lamp, but in his improved apparatus he has found it possible to dispense with this adjunct. In a German system, there are employed a number of arcs in series through which the current passes and produces rapid oscillations.

In the second general class of apparatus that has been devised to produce these undamped waves of high frequency, there can be employed, as by Professor R. A. Fessenden, another American inventor, a high speed generator designed to produce alternating current with 50,000 oscillations. Now with electric waves produced in one form or another of the desired form their

modifications under the vibrations of the human voice must next be obtained.

A high aërial wire, the antenna as the scientist with his poetic imagination terms it, is connected to earth through a coil of wire in tune electrically with a coil in the arc circuit, and the microphone or transmitter, the familiar mouthpiece and metal box we all know so well, is connected in this or a neighboring circuit. As we speak into the microphone we change the electrical resistance in the circuit and this affects the oscillations, not their frequency of course but their intensity, and this is manifested in the waves that pass out across space. After these waves have reached their destination they encounter, as in the case of the wireless telegraph, the aërial wire at the receiving end and variations in the electric current corresponding to the oscillations are detected in a number of ways by several of the finer instruments used in radio-telegraphy or some modification of them.

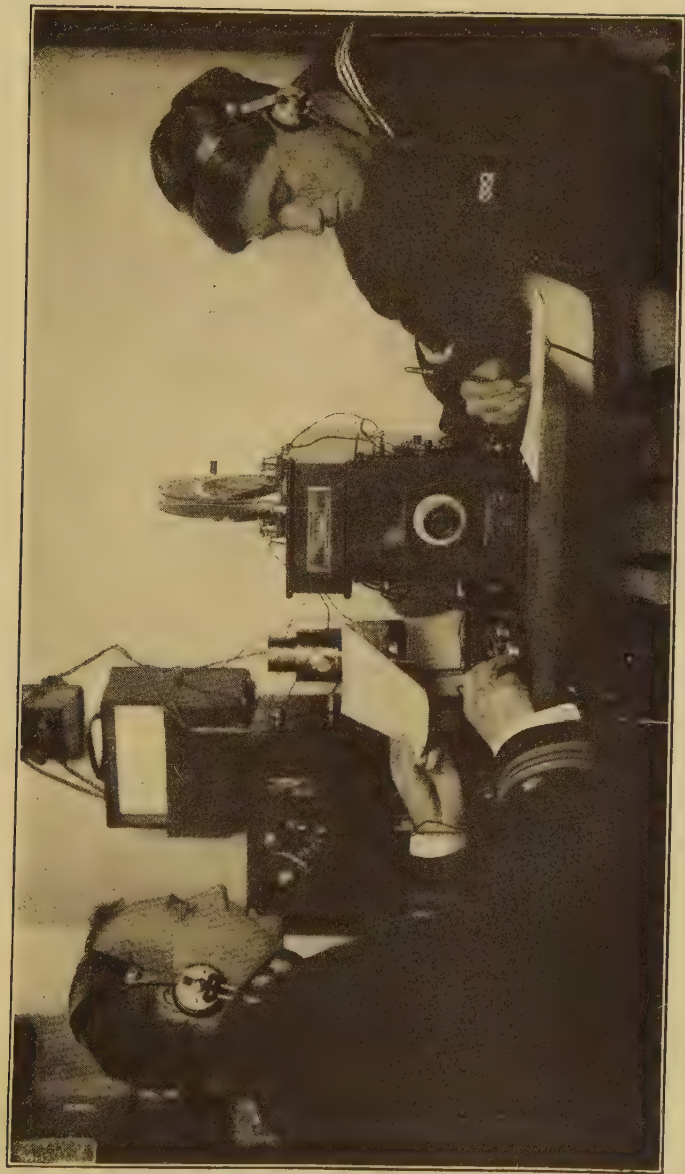
With such methods as have been outlined, Fessenden, with a 400-foot tower to support his antenna, was able to maintain wireless telephonic communication between Brant Rock, Massachusetts, and New York City, a distance of some 200 miles. De Forest talked between Chicago and Milwaukee, a distance of about 90 miles, and carried on extensive experiments involving communications between ships and shore stations along the Great Lakes. In France speech was transmitted from the Eiffel Tower, Paris, to Dieppe, a distance of 100 miles, and musical sounds were sent to the coast of Finistère, 310 miles distant. Poulsen transmitted music from Berlin to Copenhagen, 290 miles as well as over lesser distances, while in Italy various experimenters had worked up to about 250 miles.

All of this work while brilliant on the scientific side failed to achieve practical success: Wireless telephones were placed on battleships to maintain communication between various units of a fleet in the navies of several countries, but for the most part they failed to develop the degree of usefulness requisite for constant communication.

In the meantime there had been devised an important adjunct for both radio-telegraphy and radio-telephony in the form of the audion detector and amplifier. This invention was materially improved and developed, and also figured as a repeater in long-distance telephony. It consists of a highly exhaustive glass bulb containing an electrically heated filament from which electrons are emitted. Facing this there is a metallic plate or wing opposite a metallic grid carried between the filament and the plate. It serves as a detector of the etheric vibrations that are received in the antenna circuit, responding to the high frequency of oscillations required for telephonic conversations.

As a result, in 1915, using the audion and various other improvements, successful radio-telephony was established between the navy station at Arlington, Virginia, near Washington, and such distant points as the Isthmus of Panama, San Francisco, San Diego, Honolulu, and the Eiffel Tower at Paris. Furthermore, it was found possible to connect directly the long-distance telephone and telegraph wires to the radio system so that the messages would be relayed automatically from one system to the other. This achievement was one of the most remarkable in the history of electricity. It was made possible not only by improvements in the wireless receiving apparatus, but also by the development of suitable transmitting apparatus and methods for effecting and modulating the energy radiated from an antenna system in a manner corresponding to the modulations of the human voice.

The advantages of the wireless telephone readily can be appreciated whether a small station is maintained, as for communication between a vessel and the shore, or whether voice communication over large extents of ocean is desired. The wireless telephone has not yet made for itself the place of the older wireless telegraph, yet great progress has been achieved and its field of usefulness is assured. As in other fields of electricity its problems long have been realized, and each step toward their solution has been carried on as a part of patient research and careful experimentation.



THE RADIO-TELEPHONE ON THE AMERICAN BATTLESHIP. RECEIVING A MESSAGE

CONVEYANCE OF THOUGHT

From Mail Coach to Telephone

By ALFRED RUSSEL WALLACE

THE history of the progress of communication between persons at a distance from each other has gone through three stages which are radically distinct. At first it was dependent on the voice or on gestures, and a message to a friend (or enemy) at a distance could be sent only through a messenger, and was liable to distortion through failure of memory. The heralds and ambassadors of early times thus communicated orders from kings to their subjects, or conveyed messages from one king to another. Then came the invention of writing, and a new era of communication began. Letters were capable of conveying secret information and copious details, which could not be safely intrusted to the uncertain memory of an intermediary; and a single messenger could convey a large number of letters to various persons on the way to his ultimate destination. Henceforth the progress of communications was bound up with that of locomotion, and, as civilization advanced, arrangements were made for the conveyance of letters at a comparatively small cost. A post-office for the public service was first established by some Continental merchants in the fourteenth century; but it was not till the time of Charles I. that anything of the kind was to be found in England, and then it was mainly for the purpose of keeping up a communication between London and Edinburgh, and the intervening large towns, for Government purposes. It was, however, the starting-point of our existing postal system, which has been gradually extended under the direction of the King's postmaster-

general, and has continued to be a government monopoly to our day. The letters were carried on horseback till 1783, when mail coaches were first introduced; and these led to a great improvement in our main roads, and the extension of the postal service to every town and village in the kingdom.

But even with good roads and mail coaches, the actual time taken in the dispatch of a letter to a distant place was little if any less than had been possible from the earliest times, by means of relays of runners on foot or by swift horsemen. The improvement consisted in the regularity and economy of the postal service. The introduction of railways and steamships enabled much greater speed to be secured; but the greatest and most beneficial improvement in the administration of the post-office was that inaugurated by Rowland Hill in 1840. The rule then first introduced, of a uniform charge irrespective of distance, is one of those entirely new departures so many of which characterize our century, and which not only produce immediate beneficial effects, but are the starting-points of various unforeseen developments. It was founded in this case on a careful estimate of the various items which make up the cost of the carriage and delivery of each letter, and it was shown that the actual conveyance, even for the greatest distances, was the smallest part of the cost when the number of letters is large, the chief items of expense being the office work—the sorting, stamping, packing, etc.—and the final delivery, all of which are quite independent of the distance the letter is carried. The old system, therefore, of increasing the charge for postage in proportion to distance was altogether unreasonable, because the cost of conveyance was hardly perceptibly increased; and if the post-office was considered to be a public service for the public benefit only, the people had a right to demand that they should pay only in proportion to the cost. Yet the principle was not at first, and is not even now, fully carried out. For thirty years, from 1840 to 1871, the postage was increased equally with each successive increment of weight, the half-ounce letter being a penny, while one of two ounces was four-pence. But as the chief items of expense—the office work and delivery—were the same, or nearly the same, in both

WHITEHOUSE TAVERN & FAMILY HOTEL.



AN ENGLISH MAIL COACH.

cases, the double or quadruple charge was entirely opposed to the principle on which the uniform rate was originally founded. Accordingly, in 1871, when an ounce letter was first carried for a penny, the charge for two ounces was fixed at three halfpence, while four ounces was taken for twopence. This accepted and common-sense principle, however, has not yet been applied to the charges of the Postal Union, so that a letter which is a fraction over the half-ounce is charged fivepence, or double, and one over an ounce and a half tenpence, or four times that of the half-ounce letter, although an extra halfpenny would probably cover the extra cost of the service in both cases.

The same inability of the official mind to carry out an admitted principle is seen also in the case of Postal Orders. The cost to the post-office of receiving and paying money is exactly the same whether the amount is eighteenpence or fifteen shillings, and there is neither justice nor common sense in charging three times as much in the latter case. There is no risk, because the money is paid in advance; and as the amounts taken in and paid out for postal orders must be approximately equal, it is difficult to see what justification there is for making any difference in charge. The same objection applies to money orders; and as there is doubtless a certain percentage of both which, from various causes, are never presented for payment, the profit to the post-office must be greater in case of the higher amounts, which is another reason why these should not be exceptionally taxed. When the railways are taken over by the state, to be worked for the good of the community only, the principle will admit of great extension, each increment of distance being charged at a lower rate, just as is each increment of weight in our inland letters.

The third stage in the means of communication, when by means of electric signals it was rendered independent of locomotion, is that which has especially distinguished the present century. The electric telegraph serves us as a new sense, enabling us to communicate with friends at the other side of the globe almost as rapidly and as easily as if they were in different parts of the same town. The means of communication we now

use daily would have been wholly inconceivable to our ancestors a hundred years ago.

About the middle of the last century it was perceived by a few students of electricity that it afforded a means of communication at a distance; but it was not till the year 1837 that the efforts of many simultaneous workers overcame the numerous practical difficulties, and the first electric telegraph was established. Its utility was so great, especially in the working of the railways then being rapidly extended over the kingdom, that it soon came into general use; but hardly any one at first thought that it would ever be possible to lay wires across the ocean depths to distant continents. Yet, step by step, with wonderful rapidity, even this was accomplished. The first submarine line was laid from Dover to Calais in 1851; and only five years afterward, in 1856, a company was formed to lay an electric cable across the Atlantic. The cable, 2,500 miles long and weighing a ton per mile, was successfully laid, in 1858, from Ireland to Newfoundland; but owing to the weakness of the electric current, and perhaps to imperfections in the cable, it soon became useless, and had to be abandoned. After eight years more of invention and experiment, another cable was successfully laid in 1866; and there are now no less than fourteen lines across the Atlantic, while all the other oceans have been electrically bridged, so that messages can be sent to almost any part of the globe at a speed which far surpasses the imaginary power of Shakespeare's sprite Ariel, who boasted that he could "put a girdle round about the earth in forty minutes." We are now able to receive accounts of great events almost while they are happening on the other side of the globe; and, owing to difference of longitude, we sometimes can hear of an event apparently before it has happened. If some great official were to die at Calcutta at sunset, we should receive the news in London soon after noon on the same day.

As a result of the numerous experimental researches necessitated for the continuous improvement of the electric telegraph, the telephone was invented, an even more marvelous and unexpected discovery. By it, the human voice, in all its

countless modifications of equality and musical tone, and its most complex modulations during speech, is so reproduced at a distance that a speaker or singer can be distinctly heard and understood hundreds of miles away. This is not an actual transmission of the voice, as in the case of a speaking-tube, but a true reproduction by means of two vibrating disks: the one set in motion by the speaker, while the electric current causes identical vibrations in the similar disk at the end of the line, and these vibrations reproduce the exact tones of the voice so as to be perfectly intelligible. At first telephones could only be worked successfully for short distances, but by continuous improvements the distance has been steadily increased, so that in America there is a telephone line now in operation between New York and Chicago, cities about a thousand miles apart.

Those who have read Mr. Bellamy's story, "Looking Backward," will remember the concerts continually going on day and night, with telephonic connections to every house, so that every one could listen to the very best obtainable music at will. But few persons are aware that a somewhat similar use of the telephone is actually in operation at Buda-Pesth in the form of a telephonic newspaper. At certain fixed hours throughout the day a good reader is employed to send definite classes of news along the wires which are laid to subscribers' houses and offices, so that each person is able to hear the particular items he desires, without the delay of its being printed and circulated in successive editions of a newspaper. It is stated that the news is supplied to subscribers in this way at little more than the cost of a daily newspaper, and that it is a complete success.

We thus see that during the present century two distinct modes of communication with persons at a distance have been discovered and brought into practical use, both of which are perfectly new departures from the methods which, with but slight modifications, had been in use since that early period when picture writing or hieroglyphics were first invented.

In the facilities and possibilities of communication with our fellow-men all over the world, the advance made in the present

century is not only immensely greater than that effected during the whole preceding period of human history, but is even more marvelous in its results. And it is also much greater in amount than the almost simultaneous advance in facilities for locomotion, great as these have been.

EDITOR'S NOTE. — With modern methods for the conveyance of thought it must not be inferred that the old sealed letter has been neglected. The mail bag is carried on the fastest steamships and on the express trains of steam and electric railways. In the great cities of the world letters are placed in carriers for rapid transmission by pneumatic tubes to branch stations near their destination.

The twentieth century saw well-developed quadruplex and multiplex telegraphy of various forms, it saw cables worked in duplicate and a method adopted whereby messages could be relayed directly from land lines to submarine cables. It saw transcontinental telephony whereby New York could talk to San Francisco, and means whereby telegraph and telephone communication could be relayed from wire circuits to radio systems and vice versa.

The loading coil of Pupin had in large part contributed to this advance in telephony, while various relay and amplifying devices had also served in this connection. To-day the telephone is universally essential for the life of a civilized community.

For the conveyance of thought the twentieth century also saw established the use of the *aëroplane*, and regular postal routes were arranged across deserts and bodies of water. Various commercial air routes for mail, as between New York and Chicago, were proposed. Always the progress of science and invention has been concerned with the ever more rapid conveyance of thought and intelligence, and wherever there are new developments, always some effort is made to apply them in this important field.

CONVEYANCE OF THOUGHT

Wireless Telegraphy

By HERBERT T. WADE

WHEN we read the tragic account of the call of distress sent out by the wireless operator from a sinking ocean liner, we are not apt to think of the quiet laboratory of a scientist in a German university nestled among the peaceful vine-clad hills of the Rhine. Yet the story of the development of this mysterious art should have its interest, for to-day wireless or radio-telegraphy is essential to safety at sea; it contributes to our comfort in making the transatlantic passage by keeping us in constant communication with land; it supplies the mariner with time signals, enabling him to correct his chronometer and so determine his position with great precision, and thus regulate his course, and it affords a means of communication between vessels at sea that not only is convenient as well as desirable on the score of safety, but in time of war a military necessity.

All of these advantages are in addition to the practical and every-day communication of commercial and other messages over the surface of the earth, almost unlimited as to distance or accessibility. Radio-communication follows the explorer into the trackless wilds of desert or ice field, and bears down to earth the messages from the aerial navigator.

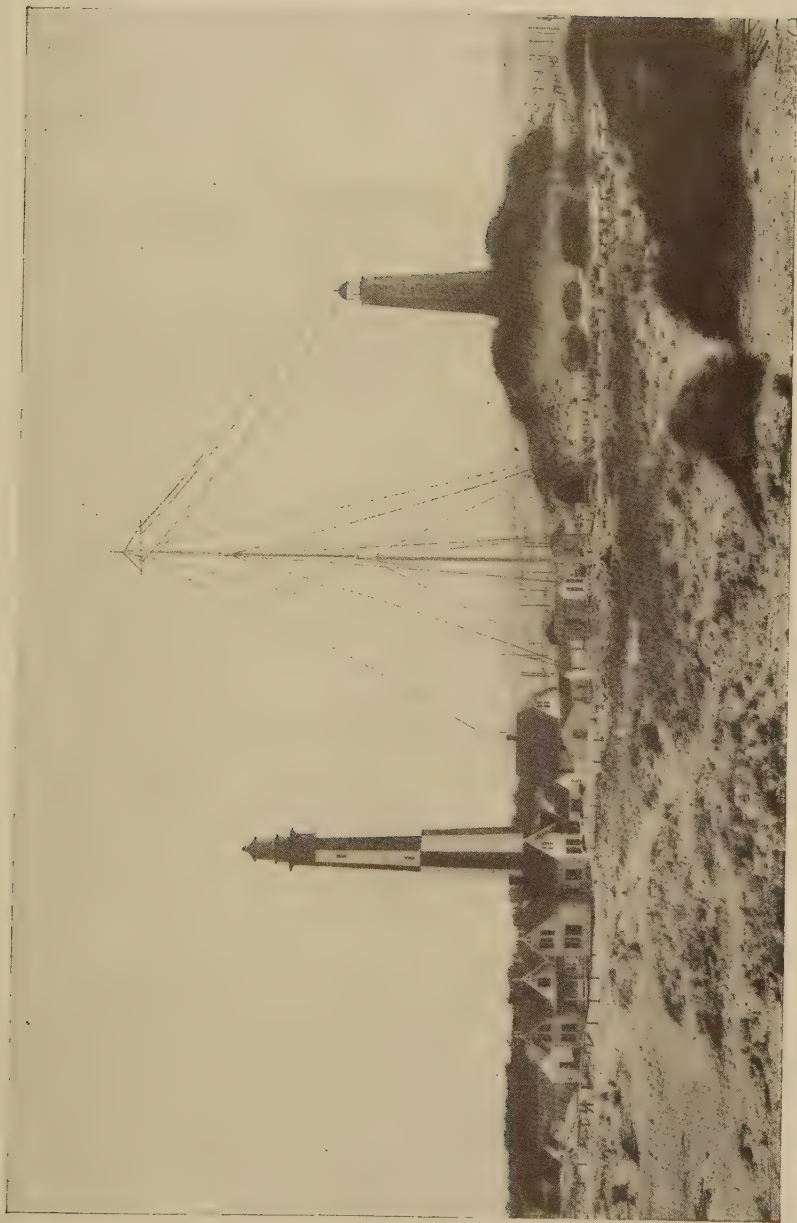
In fact, as we gaze on the aerial wires suspended on an ocean liner or from the lofty mast of a shore station, or carried above the roofs of some towering hotel or office building, we are rather prone to consider it all commonplace, though admitting its awe-inspiring mystery, and we are not

apt to think of the patient German physicist with his modest equipment working on problems and experiments bounded by the four walls of his room rather than by oceans and continents.

In 1887 Professor Heinrich Hertz, a young German physicist at the University of Bonn, was experimenting with a Ruhmkorff coil and a battery of Leyden jars, producing that sharp cracking spark of electricity familiar to most of us. A sharp brilliant spark across a gap in his conductors was obtained, and as this spark leaped across the interval he found that electrical oscillations were sent up within the circuit which gave rise to electro-magnetic waves that passed out from the wire into the surrounding space. Accordingly, if there was placed in the vicinity a circle or rectangle of copper wire with a gap, it was found that the electric waves falling upon it would establish electrical oscillations in the conductor whose presence would be manifested by a minute spark at the gap.

It was essential that the coil of wire should be in tune with the particular electrical waves generated, but it was shown that the latter not only passed through the air but through solids such as walls and floors, and were reflected by a metal plate. They could be changed in direction by a prism of pitch in the same way that a prism of glass affects light waves. In short, the study of these electrical oscillations produced many interesting results and a number of the ablest physicists all over the world repeated the experiments of Hertz and made substantial additions on their own account. Wonderful as were these discoveries made at the old university town as verifications of the prophecies of early mathematical physicists and in their relation to electrical science, it was their practical application to the transmission of intelligence that a few years later aroused the popular mind.

It was shown that these electric waves were of the same nature as the waves of light and heat and consisted of regular movements in a substance known as ether, which pervades all matter. The waves of light are very short and vibrate very rapidly, the eye being able to perceive in the form of light those that make from 4,000 to 7,000 billion per minute.



LIGHTHOUSE AND WIRELESS STATION AT OLD POINT COMFORT.

The heat waves which affect not our eyes but another sense are somewhat longer, while the electric waves, vibrate still more slowly and consequently have considerable length so that most substances are transparent to them and permit their passage.

The resonator or coil of wire that Hertz had employed was in reality part of a receiving system, and as the waves were studied their effect on various devices and arrangements was discovered. Thus Eduard Branley, a French physicist and electrician, in 1890 found that a glass tube containing iron filings placed in the circuit of the receiving wire was very sensitive to the passage of the current and that a rearrangement of the fine particles resulted which affected their electrical resistance. This made an effective detector of the waves and an interesting application of the same idea of the coherer, as it is termed, was made, in 1895, by Professor Popoff of St. Petersburg, in connection with some meteorological conclusions.

In 1896, Guglielmo Marconi, a young Italian but twenty-five years of age, who, as a student of physics had become interested in the electric waves, conceived the idea of using them for the transmission of telegraphic signals and developed the idea of combining for this purpose a system of aerial wires and a coherer with the induction coil and oscillating current as employed by Hertz. His first experiments were carried on over the fields of his father's Italian estate with crude apparatus consisting of tin boxes and aerial wires set up on poles.

His reasoning was exceedingly clear and simple, and he realized, as indeed did other physicists of the day, the nature of the waves, but in his experimental work the difficulty lay in making an apparatus that would produce the peculiar kind of wave needed and in catching or receiving this wave in a second apparatus located at a distance from the first. This he succeeded in doing with specially constructed instruments, where a rapidly vibrating current was communicated to a wire which hung from the top of a long pole or mast, or from a kite whence the waves passed out through air and earth and buildings to a second hanging wire, in which an oscillating current

was produced which passed to a receiving instrument, where the signals were registered.

Marconi's work was straightway developed in England and extensive and practical experiments were undertaken. The apparatus was installed on naval vessels and light-ships so that they could communicate with one another, and especially on nearing land. On March 27, 1899, the first wireless signals were flashed across the channel between England and France, and developments followed so rapidly that it was only seven or eight years later that Marconi had established transatlantic wireless telegraphy on a commercial basis.

In the early days of Marconi's experiments, his simple apparatus was collected in a little sending room on a seaside cliff, with which was connected a suspended wire from a signal mast. The chief feature of the apparatus was a large induction coil between the two brass balls of which crackled the electric sparks. A key similar to the ordinary telegraph key was used, and around the office were grouped Leyden jars, resistance coils, batteries and other electrical instruments and apparatus. At the very outset, the Morse code, universal in telegraph and cable work, was adopted with its familiar system of dots and dashes which could be formed into letters and words.

With each movement of the key bluish sparks would jump an inch or more between the two brass knobs of the induction coil. For one dot a single spark would jump; for one dash there would come a stream of sparks. One knob of the induction coil was connected with the earth and the other with a wire hanging from the masthead. Each one of these electric impulses oscillated through a wire and from the wire through space by vibrations of the ether were emitted the waves, traveling at the speed of light, or seven times around the earth in a second.

The receiving instruments, of course, were connected with the aerial wire when it was desired to receive, and the coherer, a device for detecting the oscillations in the aerial wire, was the fundamental part of the receiving apparatus which first made wireless telegraphy possible. Simple indeed was this

early coherer, but, without such a means of detecting the waves in the receiving aerial wire, induction coils might have snapped their messages in vain for years. In each end of this little glass tube about two inches long there was a silver plug, the two plugs nearly meeting within the tube. In the narrow space between the plugs nestled minute fragments of nickel and silver, the finest dust, siftings through silk, and these enjoy the same property of being alternately very good conductors and very bad conductors—very good conductors when welded together by the passing current to a continuous metal path, very bad conductors in their normal condition or when they fall apart under a blow from the electrical tapper which is a part of the receiving apparatus. One end of the coherer was connected with the wire which hung from the mast outside, the other with the earth and also with a home battery that worked the tapper and the Morse printing instrument.

And the practical operation is this: A single impulse comes through the ether, electric oscillations are set up in the wire and affect the coherer, causing the particles of metal to stick together or cohere. Then the Morse register, which we see sometimes in telegraph offices, prints a dot, and the tapper strikes its little hammer against the glass tube. That blow jars apart or *decoheres* the particles of metal, and stops the current of the local battery. And each successive impulse through the ether produces the same curious coherence and decoherence, and the same printing of dot or dash. The impulses through the ether would never be strong enough of themselves to work the printing instrument and the tapper, but they are strong enough to open and close a valve (the metal dust) which lets in or shuts out the stronger current of the local battery—all of which is simple enough after some one has taught the world how to do it, and before long many electricians, amateurs as well as professional workers, and even ingenious boys were repeating these experiments and reading the signals of the large stations.

The properties of the Hertzian waves when propagated on a large scale were almost unknown. Thus it was assumed that if the height of the mast was increased that the range of

operation would follow proportionately, or rather as the square of the distance to which the height of the mast was extended. Marconi was forced to realize that as soon as his method was known there was nothing to prevent any other station equipped with wireless apparatus from intercepting his messages, and this, of course, would act detrimentally to the use of the system. But with these difficulties the incentive to overcome them constantly increased, as soon as the practical value of wireless telegraphy was realized.

In 1900 he patented an arrangement by which tuning could be accomplished with greater efficiency than previously, and whereby interference of other signals and tapping by other stations were greatly reduced. This device showed it was possible to transmit two or three messages simultaneously from the same aerial wire without interference, and indicated the possibility of duplex working, or sending and receiving messages simultaneously at the same station.

After improvements in the apparatus had made possible communication of 200 miles, achieved in January, 1901, between Isle of Wight and Lizard Head in Cornwall, Marconi announced that the electric waves he had produced were able to make their way round the curvature of the earth and did not require merely a straight line direction for their propagation, and that many other considerations besides the mere height of the mast were involved. Thus in these experiments his two stations did not exceed a height of 300 feet, whereas if the curvature of the earth was involved a height of more than a mile above sea level would have been required.

The single aerial wire of his early efforts suspended from a signal mast, had by this time been superseded by a number of wires and in stations which were erected on Cape Cod and at Poldhu, Cornwall, for transatlantic experiments now begun in earnest, the aerial conductor consisted of a number of wires suspended in fan-shape between masts about 150 feet in height. Every day from Cornwall at certain hours, pre-arranged signals were sent. On the American continent at a temporary station on the coast of Newfoundland the engineers were in readiness to receive and detect these signals should

they arrive, but for a time success did not crown their efforts.

Finally, on December 12, the signals from the Cornwall station were distinctly heard by Marconi and his assistant, and while even then the message was not just as desired, yet there was no question as to the three successive dots corresponding to the letter "S," the prearranged signal, being distinctly read. Signalling across the Atlantic by electric waves had now been established.

The installation was of a rough and temporary character and further experimental work was demanded, so in the following year Marconi installed his apparatus on the steamship "Philadelphia." He employed a receiving aerial suspended from the mainmast about 190 feet above sea-level, and below in the cabin were installed receiving instruments which recorded the messages and signals on the tape of an ordinary Morse recorder. Up to 1,551 miles, readable messages were obtained and up to 2,099 miles, the waves from the station on the Welsh cliffs supplied readable test signals.

On this voyage Marconi first realized what is one of the great drawbacks in space telegraphy, namely the effect of sunlight on the propagation of electric waves over great distances. The bright sunshine, so useful in practically every other purpose, in wave telegraphy hinders the progress of the Hertzian waves, and for this reason the fog-bound shores of Canada and the cloudy air of the British Isles afford great advantages in the transmission of long distance wireless messages. While to-day wireless signals are sent at all hours the best work and greatest distances are accomplished at night.

At Glace Bay in Nova Scotia a powerful station was erected and here further experiments were made. Four large towers were erected at the corners of a square 200 feet on a side, and from their summits, 210 feet above ground, was suspended a conical arrangement of 400 copper wires, forming a huge funnel where the electric waves might be dispatched or received. In December, 1902, messages for the first time were exchanged between the Nova Scotia station and that of Poldhu. It was here that the inaugural messages to the Kings of England and Italy were dispatched, and the famous

message from President Roosevelt to King Edward found its way through space, and wireless telegraphy between the great English-speaking nations was put on a firm and practical basis. This message, sent from Cape Cod to Poldhu, traveled some 3,000 miles across the Atlantic, including about 500 miles of land, and followed an arc of 45° on the great circle.

Soon there came a radical change in the construction of the aerial wires, for Mr. Marconi believed that the effects of the electric waves could be intensified in the direction of propagation. In other words, instead of having circular waves, just as if formed from the point where the stone is allowed to fall into the water, by the use of horizontal aerial wires, the electric waves would travel in a direction, corresponding to that of the aerial system. The improvement from the horizontal aerial wires came in a most welcome manner, as greater efficiency in a given direction was obtained than by any form of aerial previously employed, so that it became the standard for all long distance stations of the Marconi Company. Instead of the induction coil, the high-frequency oscillations were produced by means of a high-tension continuous current dynamo, and a disk rotating rapidly at high speed by means of an electric motor or steam turbine was arranged so that waves of the desired frequency and length were directly available.

While the coherer with an automatic tapping device served very well for small distances, yet when the waves became weakened by travel over long distances, it was found that some more sensitive apparatus was necessary. A telephone introduced into the circuit responded to fluctuations in the current and formed an accurate and efficient means for receiving the signals, though of course not providing the certainty of the inked tape. A magnetic oscillation detector where the magnetic properties or states of magnetic metals change under the influence of the electric oscillations, later was used by Marconi and other detectors are also employed in this and other systems, but these are developed now to a point where they present considerable degree of complexity.

After a number of experiments in transatlantic communi-

cation, in October, 1907, the regular transmission of press messages between England and America was begun, and in February, 1908, ordinary commercial messages between London and Montreal were received. Since that time, with occasional interruptions due to the destruction of a station by fire, interference by storm with the land lines, and other causes not connected with radio-telegraphy, this service has been maintained, and at all times readable signals can be sent.

In 1906 Marconi found that a horizontal aerial arranged in the desired direction of transmission was better than a vertical, unless a very high mast and suspended antenna could be employed. Other inventors have worked on a directional aerial wire and it has been found possible to intensify the waves sent out in a desired direction. A directional compass or arrangement of the antennæ to denote the direction of the waves has been developed by two European scientists, Bellini and Tosi.

The modern sending station consists of a power-generating plant with either steam or gas engine or an electric motor supplied with current from some available power circuit, which drives the generator of electric power so as to produce the electrical pressure and current for the high frequency generator, a machine or device which establishes a rapid oscillation of current in the aerial wire, from which the electromagnetic waves are sent off.

A typical high power station is that of the Marconi Company at Clifden, Ireland, where there is employed a high-frequency generator in which condensers charged from the high tension batteries are discharged by projections which are fixed on a rapidly rotating wheel and which pass close to metal disks on each side of it. Each discharge produces a group of high-frequency oscillations in a primary circuit. This station maintains a directional aerial and there is a second separate station for receiving from Glace Bay the American messages without being disturbed by the simultaneous sending from the Clifden station. The distance between these stations is 2,200 miles, and they have been working for some time on a commercial basis, but not at high speed, as this is rarely

required, although automatic transmission of sixty words of five letters a minute is possible.

The reader will be interested doubtless in knowing the present range of communication of radio-telegraphy. The Marconi system has communicated without difficulty up to 3,473 nautical miles from Clifden to a ship in the tropics and to Buenos Ayres, in Argentina. Signals were received at night from Clifden at Buenos Ayres, the distance being 5,849 nautical miles. These signals were received by Mr. Marconi himself and no failures to receive any signals sent from this station were reported. During the Turkish-Italian War in 1912, communication was maintained between the Marconi station at Coltano, in Italy, and Massana, in Africa, the distance being $2,238\frac{1}{4}$ nautical miles, of which 1,999 miles was land, and much of the distance was across the tropical desert. The United States naval station at Arlington has communicated with the Pacific Coast and even as far as Honolulu. The Poulsen system has been used between Honolulu and San Francisco, a distance of over 2,000 miles. In Germany the Telefunken apparatus has transmitted signals between Nauen and Togo, in Africa, a distance of 4,000 miles.

Differences of the various systems used in radio-telegraphy are in detail rather than fundamental, except as regards the apparatus and devices that center in the high-frequency generator for producing the rapidly oscillating currents. Here there are two main classes. One where high frequency currents are produced on spark discharges which give groups of oscillations and therefore intermittent trains of ether waves, as in the Marconi and Telefunken system, and the other group where the generator produces oscillations which for practical purposes may be treated as continuous, and therefore give continuous ether waves. Various patent decisions and commercial complications have served to reduce the number of companies and the more important have acquired many patents of individual inventors for use in developing their own systems.

Necessity of communication independent of the submarine cable and land telegraph between its fleets and with its insular

possessions, impressed itself on the Government of the United States and particularly on the Navy Department. Accordingly after the experience derived from the extensive use of wireless on the battleship cruises, it was determined to erect a chain of wireless stations so that every ship or possession of the United States could be kept in communication with Washington. Each of the stations was designed with a semi-radius of operation of 3,000 miles or more, and the first to be constructed was the home station at Arlington where three lofty steel towers in the form of an isosceles triangle were built. One of these towers was placed at the apex of the triangle, 650 feet in height, or rising 95 feet higher than the Washington monument, while the other towers, to which the antennæ or aërial wires are strung from the highest tower, are each 450 feet in height. From this station it is possible to communicate with the ships of the navy and with Porto Rico, Cuba and Panama, and to send out time signals.

In the merchant marine, also, particularly on the large passenger steamships, wireless telegraphy has found perhaps its widest application and now nearly 2,000 vessels plying the seas are so equipped. Hardly a point on the high seas is so remote as to be beyond reach of such signals and it enables help to be called in case of danger. The first time this was strikingly illustrated was in the collision between the "Florida" and the "Republic" with the subsequent sinking of the latter vessel on January 23, 1909. The wireless signal "C. Q. D.," the danger call of the seas, later changed to "S. O. S.," sent out from the great liner, was able to bring to its assistance enough ships to care for all the passengers and to pick up the boats in which many had taken refuge. Immediately the news was known on two continents, and it was not several days, as previously in the case of "La Bourgogne," before two shocked continents received the intelligence.

Even in the earliest stages of wireless at sea it was realized that the danger call should take precedence over any other message and whatever the steamer in use, this signal should be passed from ship to ship or from ship to shore station. A few moments usually intervene after even the worst accidents

at sea, when it is possible for the operator to send out this distress signal so that help can be forthcoming directly. In fact, it was made compulsory to have ready for use storage batteries or gasoline engines to work the high-frequency generators so that they should be independent of the main boilers and engines of the vessel.

Gradually wireless equipment became recognized as an essential element of the equipment of a vessel, and the United States Congress in 1910 made it unlawful for ocean-going steamers carrying fifty or more persons to leave an American port without having a wireless equipment able to communicate at least 100 miles.

Were further evidence of the value and necessity of wireless at sea needed it is found in the eventful voyage of the *Titanic*, which, crashing into a submerged iceberg, sank a few hours later, on April 15, 1912. Immediately after the collision, when it was found that the ship was in a sinking condition, the latitude and longitude of its position were worked out and the code distress signal "S. O. S." was sent out as long as power was available to operate the apparatus. The call for aid was heard by the Cape Race station and by some eight steamships at distances of from 20 to 512 miles, but particularly by the Cunard steamship *Carpathia*, on her way from New York to Gibraltar and Genoa. Fifty-six miles away when the operator in the wireless room heard the tragic message, the *Carpathia* was put about and brought to the scene of disaster in time to save those of the passengers that had taken to the boats. With this appreciation of the great advantage of the wireless, the previous United States statute was amended, requiring not only the maintenance of equipment for radio-communication, but at least two operators skilled in its use, with one constantly on watch, and an auxiliary power supply independent of the vessel's main electric power plant, sufficient to enable signals to be sent for at least four hours. With the ravages of the German submarines in the great war the wireless prevented even greater loss of life.

Up to the time of the great European War, the develop-



WIRELESS TELEGRAPH STATION ON AN U. S. BATTLESHIP.

ment of wireless telegraphy had made steady progress and improvement. Of course it was found necessary to require official license for each of the many stations and investigators, and also to provide suitable regulations and restrictions for the commercial companies. The various governments in connection with their fleets sought to increase the range of wireless communication and to provide that at all times their naval vessels should be in communication with their bases. In the United States, the naval station at Arlington, Virginia, has exchanged signals for instance with Paris and with Honolulu. For the advantage of mariners, wireless time signals were sent out over the oceans so that chronometers could be corrected with precision.

In commerce a distinct field has been found for radio communication. True, it has not supplanted the submarine cable as its early advocates had prophesied, but on later consideration there was no reason why it should, as a distinct field was to be available for each. Likewise on land the wire routes of communication in no degree had fallen into disuse. In fact as with many new inventions, the development of wireless rather led to the improvement of previously existing devices to which it might have been considered a competitor. But of one field wireless was distinctly master, namely, in communication between ships and shore over considerable distances, for not only commercial messages but storm warnings and various other despatches could be sent, and at no point need a ship at sea be out of range of communication with the land.

With the outbreak of the great war the belligerent and other countries immediately took possession of all unofficial wireless stations. The scout ships of the naval fleets reported the results of their observations, while dirigibles and *aéroplanes* were fitted to communicate with their bases or with ships. To protect commerce from submarines, it was possible thus to bring up destroyers to parts of the sea where these craft were operating, while on land the position of artillery, their ranges, and other information could be transmitted from the *aéroplane*.

CONVEYANCE OF THOUGHT

Sound

By ELISHA GRAY

VIBRATION is an oscillation, or shaking to and fro, made by a stationary body (like a pendulum, or a stretched wire) when disturbed from its equilibrium or rest. When this motion is slow—as a pendulum—it is called oscillation; when rapid—as of a wire or tuning-fork—it is called vibration. The latter term is used also in describing the action of a disturbed fluid—as of water, air, or ether—when it results in a wave-motion, a phenomenon so familiar that it needs no definition. The effects of Sound, Light, and Heat are all produced through vibrations of the medium transmitting the disturbing force. We will begin with the first named.

Sound is one of the important mediums through which the inner man communicates with the outer world. It may be defined as Motion or Vibration, in its objective or outer manifestations, and as Sensation in its effect upon our consciousness through the medium of the organs of hearing.

There are many avenues to the brain that are in touch with the outer world through the medium of the five senses. Through all of these avenues the same general vehicle is used to carry intelligence to the brain of the percipient—to wit, motion.

It is motion of the optic nerve that carries to the brain the sensation of light. It is motion of the gustatory nerve that carries to the brain the sensation of taste. It is motion of the olfactory nerve that carries to the brain the sensation of smell. It is motion of the nerves of feeling that carries the sense of

touch; and it is a motion of the auditory nerve that gives us the sensation of sound.

Nothing but sound can be transmitted through the auditory nerve; and nothing but light through the optic nerve. The same is true of the other avenues to the brain: you cannot smell with your tongue or taste with your nose, although the sense of taste and smell are very closely allied; that is, we often taste and smell at the same time, but attribute the sensation all to taste. Put a cinnamon drop on your tongue and hold your nose and you will taste only sugar. You get the taste of cinnamon only when the nasal passages are open. We really taste and smell at the same time, in some instances, and call it all taste. Each special nerve has its special use. If we have lost one of these highways between the outer world and the inner self, by so much we are dead to physical things.

All the phenomena of sound, outside of the point where we perceive it, are simply motions of some character. The different kinds of sound are infinite, but each sensation of sound that differs from another has its correlative in the air outside of the ear as a peculiar form of motion. For instance, if some one out of sight, but not out of hearing, should sound a note on a violin, you would say that you heard a violin; but if some one should sound a note, of the same pitch, on an organ, you would say that you heard an organ. What is the difference? Simply that the kind or quality of the motion made by the violin differs from that of the organ; hence the difference of the sensation. What this difference is will be fully explained in its proper place.

Let us now go back and follow out the course of a single sound-impulse from its source to the ear, and through it to the brain—the seat of sensation.

Let us fill a soap-bubble with oxygen and hydrogen gases in the proportion of two parts of hydrogen to one of oxygen. If we ignite it the result will be an explosion. When the ignition takes place there is a sudden generation of heat, which suddenly expands the air, causing it to be highly rarefied at the point of explosion. The air immediately surrounding it is driven violently outward in every direction. The first layer of

air-particles, surrounding the bubble, is driven against the second and then swings back to its place, for the force that drove it outward is no longer present. The second layer swings against the third and the third against the fourth, and so on; each layer after making its excursion outward returns to its original position. The air-particles are not fired at the ear as from a gun; they simply vibrate to and fro. The sound-pulse moves outward like an expanding globe at the rate of about 1,100 feet per second in air, the speed depending upon the medium through which it travels.

Some notion of the movement of a sound-pulsation may be had by watching the expanding ring made by a pebble when dropped into a pond of smooth water. A still clearer idea may be had by laying a number of billiard-balls in a groove, so that they are in close contact. Now tap on one of the end balls sharply and watch the effect. None of the balls seem to have changed position except the end one, opposite from the one that received the blow. This one has rolled away from the others. The first ball struck delivered its blow to the second, and so on to the last. This one, having nothing to deliver its blow to, rolls away under the impetus given to it by the ball next to it. This is precisely what takes place in the air, only with balls infinitely small, as compared with the billiard-balls. Each ball has made a pendulous motion; it has moved forward a short space and returned to its original position. The distance it has moved forward and back is called the amplitude (largeness—size) of its motion or vibration, and, other things being equal, the loudness of a sound varies as the square of the amplitude of the vibratory impulse.

Starting again with our soap-bubble, from the point of explosion: the same impulse moves in every direction—like light from a single luminous point—through the air, but produces no sensation till it strikes an ear. The membrane of the ear is made to vibrate or swing back and forth, which, in turn, moves the inner mechanism of the ear—for it is a mechanism, and a most wonderful one—which finally communicates its motion to the auditory nerve, which reaches into the brain, where the motion is translated into a sensation that we call

Sound. What is this mysterious blending between the activities of the outer world and the sense-perception of the inner consciousness? All the combined wisdom of philosophers and sages has never solved the problem. Much has been written, but no explanation, only words, words, words. We have to be satisfied with studying the phenomena only, of natural law, for that is all we can really know about it. We perceive the facts, but cannot explain how the physical is translated into mental consciousness.

Sound is transmitted either through gases, liquids, or solids, but the velocity is determined by the elasticity of the medium through which it is transmitted. Numerous experiments have been made to determine the velocity of sound when transmitted through different media, and long tables on this subject may be found. The following table will give a general idea of the velocity of sound through solids, liquids, and gases:

The velocity through air, 1,100 feet per second.

The velocity through water, over four times that of air.

The velocity through pine wood, ten times that of air.

The velocity through iron, seventeen times that of air.

These figures are only approximately correct, as the velocity of sound in gases varies with changes of temperature. Again, a loud sound travels faster than a feeble one. A striking instance of this fact is shown in an experiment made by some Arctic explorers. Sounds, even moderate ones, are heard to comparatively great distances over smooth ice. A cannon was fired, and the observer, who was quite a distance from the gun, heard the boom of the cannon before he heard the order to fire, which of course, was given first.

Sound cannot be transmitted through a vacuum, as shown by the following familiar experiment made by a philosopher named Hawksbee as far back as 1705. Place a bell that is operated by a clockwork inside of the receiver of an air-pump. This receiver is a large bell-glass, ground to make an air-tight fit on the bedplate of the air-pump. Suspend the bell inside the receiver, by some kind of cord that will not transmit sound, and then set it to ringing. At first it will ring as loudly as

though it were in the open air. Now, work the pump and exhaust the air. The sound will grow fainter until a nearly perfect vacuum is obtained, when the sound will cease, although the hammer is still striking the bell the same as at first. Now let the air in and the ringing is heard again.

Reasoning from the above experiment, one should expect that sounds would not be as loud on high mountains as down on the sea-level. This is found to be the case, because the air at very high elevations is much less dense and there are fewer air molecules in a given area to strike upon the drum of the ear.

For the same reason sound will be carried farther and seem louder on some days than others. When the barometer is high it shows that the air is dense, and dense air is a better medium for sound transmission than rarefied air, at least so far as loudness is concerned. The experiment with the bell in a vacuum shows that sound is transmitted only through material of some kind that may be made manifest to our senses. It also shows that matter, as we understand it, is not necessary for the transmission of light and radiant heat, for both light and radiant heat will pass through the vacuum, when the bell will not sound, as readily as through the air.

Sound is reflected like light. It may be focused on a single point, like light or radiant heat, by means of concave reflectors. It tends to move in straight lines, but will in a degree go around an object; yet a large object casts a distinct sound-shadow, if we may use the term. If we throw an elastic ball on the floor with considerable force it will rebound at the same angle at which it was moving when it struck the floor. The direction it was moving before it struck is called the angle of incidence, and the direction it moves after that is called the angle of reflection. Sound and light obey this law. Sound waves are reflected from a polished surface the same as light waves, and they obey the same laws in the matter of focusing and dispersion that light does.

A striking instance of sound reflection may be noticed any time during the passage of a thunderstorm. Whoever has stood on a mountain top towering 15,000 feet above the sea and from this view-point of a cloudless sky and bright sunshine has

looked down upon a storm-cloud hovering far below against the side of the mountain, and stretching far across the valley, has witnessed a scene of grandeur that no language can adequately describe. It is from a view like this that one gets an accurate conception of cloud-form as it really is. Great billowy mountains, whose crests are tipped with purest silver and whose shapes are as multiformed as the leaves of the forest and as numberless as the sands of the desert!

A storm-cloud as seen from above, under the full rays of the sun, appears to be, and doubtless is, made up of a series of clouds that may or may not touch each other. During the progress of the storm one or more of the clouds becomes surcharged from time to time with electricity, when it seeks to establish an equilibrium, by discharging into the earth or into another cloud. This discharge causes a great sound wave to flow out from the point of disruption, much louder than the booming of the heaviest cannon, and it travels, as we have seen, at the rate of 1,100 feet per second through the air in all directions. Suppose we are standing one mile from the point of disruption in the cloud, watching the operation of nature's great electrical power-plant. We see a flash of lightning, and in a little less than five seconds we hear the thunder; and, although there has been only a single report like the firing of a cannon, it seems to us to be a great many following each other in rapid succession. We have already seen that a sound wave moves out like an expanding globe from a common center, which is the origin of the sound impulse. A part of the wave coming from the cloud moves in a direct line toward the observer. When the wave strikes his ear there is the sensation of an explosion of great power, and this is followed by others in rapid succession, for several seconds, each succeeding one growing weaker until it dies out in what seems to be a distant roll of thunder. The explanation is this: Beyond the cloud where the discharge took place, and farther away from the observer, is another cloud with a large reflecting surface, and beyond that a second, a third, and so on, it may be, for many miles. Each one of these surfaces reflects back to the ear of the observer a part of this great sonorous impulse; but as a

part of the wave that is reflected, is reflected from the successive cloud surfaces that are farther away, and no two of them the same, the reflected sound keeps on coming to the ear at disjointed intervals, because the distances are constantly increasing and not uniform. If the first cloud beyond the point of explosion is five hundred and fifty feet farther away from the observer, the second explosion, or the first reflected explosion, will occur one second after the first; for it has to travel five hundred and fifty feet away, and then retrace the distance. So, by that time, the original wave will have one-fifth of a mile the start. This is the cause in many instances, and the chief cause in most cases, of the phenomena of rolling thunder.

CONVEYANCE OF THOUGHT

How the Telephone Talks

By ELISHA GRAY

EVERYBODY knows what the telephone is, because it is in almost every man's house. But while everybody knows what it is, there are very few (comparatively speaking) who know how it works.

When any one utters a spoken word, the air is thrown into shivers or vibrations of a peculiar form, and every different sound has a different form. Therefore, every articulate word differs from every other word, not only as a shape in the air, but as a sensation in the brain, where the air vibrations have been conducted through the organ of hearing; otherwise we could not distinguish between one word and another. Every different word produces a different sensation because there is a physical difference, as a shape or motion, in the air where it is uttered. If one word contains 1,000 simultaneous air motions and another 1,500, you can see that there is a physical or mechanical difference in the air.

The construction of the simplest form of telephone is as follows: Take a piece of iron rod one-half or three-quarters of an inch long and one-quarter inch thick, and after putting a spool-head on each end to hold the wire in place, wind it full of fine insulated copper wire; fasten the end of this spool to the end of a straight-bar permanent magnet. Then put the whole into a suitable frame, and mount a thin circular diaphragm (membrane or plate) of iron or steel, held by its edges, so that the free end of the spool will come near to but not touch the center of the diaphragm. This diaphragm must be held rigidly at the edges.

Now if the two ends of the insulated copper wires are brought out to suitable binding-screws, the instrument is done.

The permanent steel magnet serves a double purpose. When the telephone was first used commercially, the instrument now used as a receiver was also used as a transmitter. As a transmitter it is a dynamo-electric machine. Every time the iron diaphragm is moved in the magnetic field of the pole of the permanent magnet, which in this case is the free end of the spool (the iron of the spool being magnetic by contact with the permanent magnet), there is a current set up in the wire wound on the spool; a short impulse, lasting only as long as the movements lasts. The intensity of the impulse will depend upon the amplitude and quickness of the movement of the diaphragm. If there is a long movement there will be a strong current, and vice versa. If a sound is uttered, and even if the multitude of sounds that are required to form a word, be spoken to the diaphragm, the latter partakes in kind of the air motions that strike it. It swings or vibrates in the air, and if it is a perfect diaphragm it moves exactly as the air does, both as to amplitude and complexity of movement.

All these complex motions are communicated by the air to the diaphragm, and the diaphragm sets up electric currents in the wire wound on the spool, corresponding exactly in number and form, so that the current is molded exactly as the air waves are. Now, if we connect another telephone in the circuit, and talk to one of them, the diaphragm of the other will be vibrated by the electric current sent, and caused to move in sympathy with it and make exactly the same motions relatively, both as to number and amplitude.

It will be plain that if the receiving diaphragm is making the same motions as the transmitting diaphragm, it will put the air in the same kind of motion that the air is in at the transmitting end, and will produce the same sensation when sensed by the brain through the ear. If the air motion is that of any spoken word, it will be the same at both ends of the line, except that it will not be so intense at the receiving end; it is the same relatively. And this is how the telephone talks.

I have said that the permanent magnet had two functions.

In the case of the transmitter it is the medium through which mechanical is converted into electrical energy. It corresponds to the field magnet of the dynamo, while the diaphragm corresponds to the revolving armature, and the voice is the steam engine that drives it. In the second place, it puts a tension on the diaphragm and also puts the molecules of the iron core of the magnet in a state of tension or magnetic strain, and in that condition both the molecules and the diaphragm are much more sensitive to the electric impulses sent over the wire from the transmitter. At the present day this form of telephone is used only as a receiver and the magnet used is of the horseshoe form with both poles close to the diaphragm.

Transmitters have been made in a variety of forms, but there are only two generic methods of transmission. One is the magneto method — the one we have described — and the other is effected by varying the resistance of a battery current. The former will work without a battery, as the voice acting on the wire around the magnet through the diaphragm creates the current; in the latter the current is created by the battery but molded by the voice. In the latter method the current passes through carbon contacts that are moved by the diaphragm. Carbon is the best substance, because it will bear a wider separation of contact without actually breaking the current.

The fundamental principles of receiver and transmitter have been preserved in modern instruments, but there have been vast improvements in detail, and the auxiliary equipment has become exceedingly complex. Telephone engineering is now a distinct branch of electrical engineering, and not only the design, construction, and installation of telephone equipment require the service of experts, but the mere matter of maintenance is specialized and involved.

At the beginning the simple telephone as outlined was intended and employed merely for direct communication on private lines, but as early as 1877 G. G. Hubbard appreciated the fact that the fullest use of the instrument best could be secured by the establishment of exchanges where

any single instrument could be connected with any other of a given group. Accordingly, the switchboard and the central station were developed, and they are quite as important as the receiver and the transmitter.

When the telephone was first arranged for commercial use, it was realized that a signaling device to call the subscriber to the instrument must be included. For many years it consisted of a small electric generator or magneto where a few vigorous turns of a crank would revolve an armature and transmit a current of sufficient tension to ring an electric bell connected with the instrument, or actuate a drop or other signal at the distant station or exchange.

The switchboard, ordinarily operated by one or more quick-witted, nimble-fingered young women, is indeed an important consideration in any telephone system. When the distant subscriber turns the crank, or in a more improved instrument simply takes the receiver from the hook, a little drop or shutter with an appropriate number falls, or a small incandescent lamp glows and calls the attention of the operator to the fact that the subscriber wishes to converse. The operator with a flexible cord and plug makes a connection between her instrument and the subscriber, and learns the name or number of the person with whom communication is desired. The next step is to make that connection, and by means of another flexible cord the two circuits are joined so that there is direct communication between the two sets of instruments.

In great city exchanges a switchboard is a marvel of complexity, and the work of the operators is highly organized. The signal indicating that the subscriber desires the attention of the operator usually is a small incandescent lamp, and each operator can take care of about 300 subscribers whose calls she must answer, and a switchboard can be made large enough for about 10,000 subscribers.

An important development is the use of a large common battery at the central station and the elimination of the magneto and local battery at the subscriber's instrument. This decreases materially the cost of the subscriber's in-

stallation and also saves time for him as well as for the operator. The modern telephone line employs a metallic circuit in place of the single wire and the ground return, and it has been found essential for long-distance communications to employ the more expensive copper wire instead of the galvanized iron wire used in the early days of the art. Soon after 1880 experimental circuits of hard drawn copper wire were operated between New York and Boston, and by 1902 a wire circuit with 9,200 miles of wire was established between New York and Chicago. Later this was extended to Omaha and Denver, and on January 25, 1915, direct telephone communication between New York and San Francisco was established.

Telephony over long distances and through considerable length of cable, either underground or water, largely has been made practicable by the ingenious device which prevents the attenuation of the minute electric currents flowing through the telephone conductors. On an underground line so-called loading coils are located at intervals of about one thousand feet, while on the overhead line they are placed about two and a half miles apart. These coils have certain electric properties known as inductance and capacity to a determined degree, and facilitate the transmission of the electric waves with a minimum loss of energy.

Another device which was a long time being realized in telephony is the repeater or telephonic relay. The most successful form has been the vacuum repeater borrowed from wireless telegraphy. By this device the energy received in the telephone circuit can be amplified and sent out over the next circuit.

Any consideration of the telephone would be incomplete if mention were not made of the fact that over a single wire circuit both telegraphic and telephonic messages can be sent. This is due to the fact that the interruptions in the telegraph transmission of signals are so slow in comparison with the rapid modulation of the telephonic currents that the latter are not appreciably affected.

LABOR-SAVING MACHINERY

The Wonder-Working Wheel

By ALFRED RUSSEL WALLACE

THE invention and partial development of much of our modern machinery dates from the last century, and our most advanced appliances for the manufacture of the various textile fabrics and hardware are mostly improvements of, or developments from, the older machines. These, taken in connection with the great improvements in steam engines, have multiplied many times over the efficiency of human labor, but do not otherwise specially interest us here. There are, however, a few inventions which have the character of quite new departures, since not only do they greatly diminish labor but they perform, by mechanical contrivances, operations which had been supposed to be beyond the power of machinery to execute. The more prominent of these are the sewing machine, the typewriter, and the combined reaping, threshing, and winnowing machine, of which a brief account will be given.

The sewing machine, now so common, exercised the ingenuity of mechanics for a long period before it arrived at sufficient perfection to be suitable for general use. The earlier machines were for embroidering only; then, about 1790, one was made for stitching shoes, and other leather work, but it does not seem to have come into general use. A crocheting machine was patented in 1834; somewhat later one for rough basting; but it was not till 1846 that the first effective lock-stitch sewing machine was made by Elias Howe, of Cambridge, Mass. Henceforth sewing machines were rapidly improved and adapted to every variety of work; but the difficulty of the problem to

be solved is shown by the unusually long process of gradual development, much of the mechanical talent of both hemispheres being occupied for nearly a century before the various machines so familiar to-day were perfected. There are now special machines for making button-holes and for sewing on buttons, for carpet-sewing, for pattern-sewing, for leather work, and for the special operations required in the making and repairing of shoes. Boot and shoe-making by machinery, in large factories, has entirely grown up since the sewing machine was proved to be adapted for almost every kind of sewing work. As a result, machine-made boots and shoes are very cheap, but they are usually of inferior quality to the old hand-made articles; and first-class work is quite as dear as it was fifty or sixty years ago, or even dearer.

The typewriter is a still later invention, and though perhaps less difficult than the sewing machine, yet it involves more complex motions and adjustments, so that the perfection it has so quickly attained is very remarkable. If we consider that about sixty separate types, including small letters, capitals, spaces, stops, etc., have to be so arranged and so connected as to be brought in any order whatever to a definite position, so as to form the successive letters and spaces in lines of printed characters, and then, being properly inked, must be brought into contact with the paper so as to produce a clear impression, and that all the motions of the machinery required must be the result of a single pressure on a key for each letter, following one another as rapidly as possible, we shall have some idea of the difficulties which have had to be overcome. Yet, so great are the resources of modern mechanism, and the ingenuity of our mechanists, that the required result has been attained in many different ways, so that we may now choose between half a dozen forms of typewriters, no one of which seems to be very markedly superior to the rest.

More important, perhaps, to mankind generally, are the harvesting machines, which render it possible to utilize one or two fine days to secure a harvest. Reaping machines have long been used in this country, and they were followed by combined reapers and binders, which left the crop ready for carting

to the barn. But this, when the distance was great, did not save the grain from injury by wet, besides requiring much labor and a careful process of stacking to preserve it. In America a harvesting machine has been brought to perfection, which not only reaps the grain, but threshes it, winnows it, and delivers it into sacks ready for the granary or the market, at one operation. This machine, with two men, will, in one fine day, secure the crop from ten or fifteen acres, with a minimum of labor. In the great wheat fields of California and Australia, with an almost uniformly dry climate at harvest time, it is this saving of labor which is the chief consideration; but in our treacherous climate, where a few days' delay may mean the partial or complete ruin of the crop, such machines will be doubly valuable by enabling farmers to utilize to the utmost every fine day after the grain is ripe. I had the pleasure of seeing this wonderful machine at work in California in 1887. It was propelled by sixteen small mules harnessed behind, so as not to be in the way; but steam power is now used. Considering what it effected, it was wonderfully light, compact, and simple; and when agriculture is treated as a work of national importance, such machines will render us, to a considerable extent, independent of the weather, and will therefore become a necessity.

The three mechanical inventions here briefly described were conceived in the first half, and brought to perfection in the second half of the century. They each mark a new departure in human industry, inasmuch as they effect, by means of machinery and at one operation, what had previously been performed by human labor directed by a hand or arm rendered skillful by long practice, and sometimes requiring several distinct operations. They had been thus performed during the whole preceding period of human history, or so long as the particular kind of work had been done; so that, though of less general use and of less importance, they have the same distinguishing features which we have found to characterize our new methods of locomotion.

There are, of course, innumerable other remarkable mechanical inventions of the century in almost every department of in-

dustry — such as the Jacquard loom for pattern-weaving, revolvers, and machine guns, iron ships, screw propellers, etc.; while machinery has been extensively applied to watch-making, screw-cutting, nail-making, printing, and a hundred other purposes. But none of these are of very high importance in themselves, or possess the special characteristics of being new and quite distinct departures from what has been done before, and they cannot therefore rank individually among those greater discoveries which pre-eminently distinguish the nineteenth century.

EDITOR'S NOTE. — While Dr. Wallace has called a proper attention to the importance of such labor-saving machinery as the sewing machine, the typewriter, and the combined reaping, threshing, and winnowing machine, yet in their importance the twentieth century has developed these machines far beyond any promise of their earlier use. Not only has the sewing machine largely supplanted hand labor, but it has made possible the establishment of vast industries where power-driven sewing machines are used in turning out clothes for the masses, so that making clothes in the household has all but become a lost art, and not only men but women can secure useful and attractive apparel either from the local stores or through the parcel post.

With the clearly printed characters of the typewriter no one will spend time and eyesight in deciphering hieroglyphics or the fine scrolls of the expert penman. But even more, the typewriter has been combined with the mechanical adding machine, and we find that the bookkeeper at a single operation is able to list his items, total the various columns and print the amounts with speed and accuracy. Even the familiar telegraph is now combined with the printing machine.

The reaper is still required, but no longer has it to be driven by long strings of horses or mules, for now the automobile tractor drags behind it a complete mechanical equipment from which it is possible to discharge directly the sacks of grain ready for transport.

LABOR-SAVING MACHINERY

Printing, Past and Present

By JOHN TIMBS

THE inquirers into the origin and history of this almost ubiquitous "noble craft and mystery," would seem to have arrived at this conclusion—that it is difficult to say at what period of time the art of printing did not exist. The simplest and most natural mode of conveying an idea is by the reproduction of similar appearances of the same surface; and whether this be by a hand or foot upon snow, or by the pressure of wood or metal upon paper or vellum, it is alike printing. Accordingly, we find evidence that nearly four thousand years since, a rude and imperfect method was certainly practiced. First, seals were impressed upon a plastic material; next, symbols or characters were stamped upon clay in forming bricks (as practiced in Babylon), cylinders, and the walls of edifices. Of this art, Wilkinson and others have brought examples from Egypt; and Rawlinson and Layard from the ruins of the buried cities of Asia. Not only have the inscribed bricks been found, but the wooden stamps with which they were impressed; of these, numerous specimens are in the British Museum. Here also may be seen several instruments presenting a singular instance how very nearly we may approach to an important discovery, and yet miss it. These are brass or bronze stamps, having on their faces inscriptions in raised characters reversed. To the back has been fastened a handle, a loop, a boss, or a ring. One use of these stamps has evidently been to print the inscription, by aid of color, upon papyrus, linen, or parchment; and, as the inscriptions show these stamps to have been of the

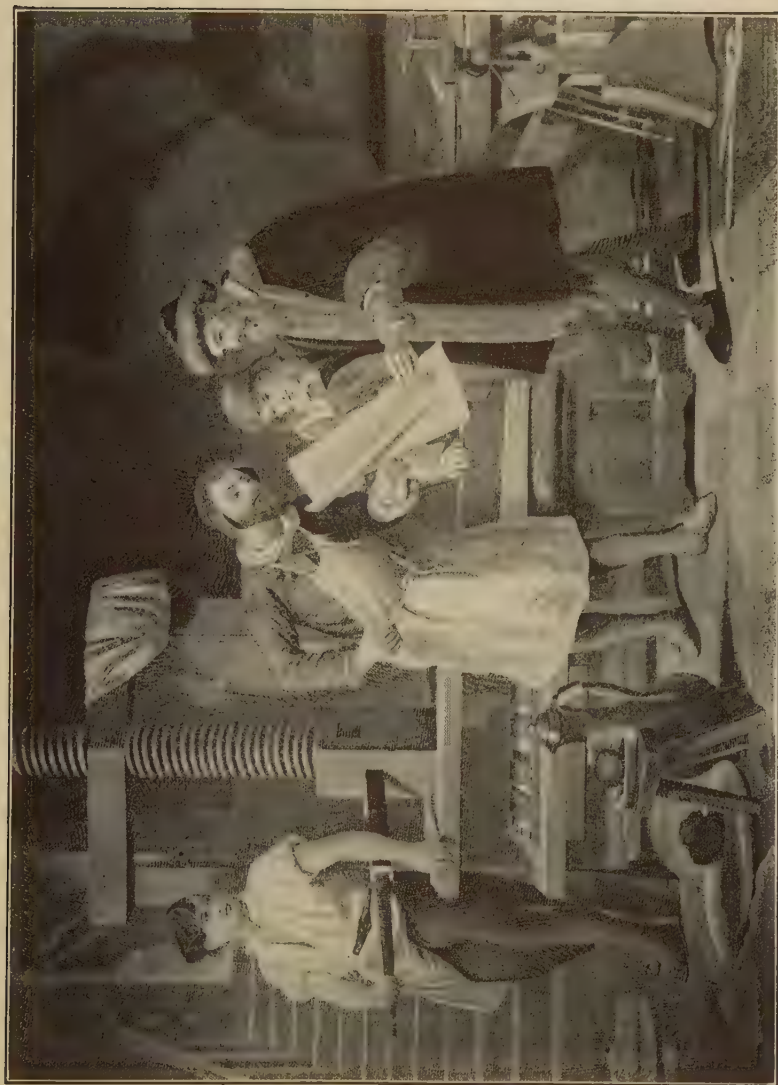
period when literature had become one of the pursuits of the great, and the copying of books was a slow and expensive process, it is strange that the Romans, by whom these signets were used, should not have improved upon them by engraving whole sentences and compositions upon blocks, and thence transferring them to paper. The Chinese printing from blocks at this day closely resembles the old Roman; and they assert that it was used by them several centuries before it was known in Europe—in fact, fifty years before the Christian era.

A vast interval elapses between the above attempts and the next advance—engraving pictures upon wooden blocks, invented toward the end of the thirteenth century by a twin brother and sister of the illustrious family of Cunio, lords of Italy: these consisted of nine engravings of the “Heroic Actions” of Alexander the Great, and, as stated in the title-page, “first reduced, imagined, and attempted to be executed in relief, with a small knife, on blocks of wood”; “all this was done and finished by us when only sixteen years of age.” This title, if genuine, presents us at once with the origin, execution, and design of the first attempts at block printing. The next earliest evidence is a decree found among the archives of the Company of Printers at Venice, dated 1441, relating to playing cards, printed from wood blocks, the impressions being taken by means of a burnisher. Then, instead of a single block a series of blocks was employed, in engravings of the *Biblia Pauperum*, the text being printed from movable types.

We have now reached the practice of printing, in the present sense of the term. The invention of the movable types is disputed by many cities, but only three have the slightest claim—Haarlem, Strasburg, and Mentz: Haarlem for Lawrence Koster, who, when “walking in a suburban grove, began first to fashion beech bark into letters, which being impressed upon paper, reversed in the manner of a seal, produced one verse, then another, as his fancy pleased, to be for copies for the children of his son-in-law.” Next, he, with his son-in-law, devised “a more glutinous and tenacious species of writing ink, which he had commonly used to draw letters; thence he expressed entire figured pictures, with characters

added," only on opposite pages, not printed on both sides. Afterward he changed beech blocks for lead, and then for tin. The tradition adds that an unfaithful servant, having fled with the secret, set up for himself at Strasburg or Mentz; but the whole story, which claims the substitution of movable for fixed letters as early as 1430, cannot be traced beyond the middle of the sixteenth century, and is generally discredited as a romantic fiction. Nevertheless some have believed that a book called *Speculum Humanæ Salvationis*, of very rude wooden characters, proceeded from the Haarlem press before any other that is generally recognized. Whether movable wooden characters were ever employed in any entire work is very questionable; they appear, however, in the capital letters of some early printed books. "But," says Hallam, "no expedient of this kind could have fulfilled the great purposes of this invention, until it was perfected by founding metal types in a matrix or mould; the essential characteristic of printing, as distinguished from other arts that bear some analogy to it."

The invention is now unhesitatingly ascribed to John Gutenberg, a native of Mentz; the evidence of which does not rest upon guesses from dateless woodcuts, but upon a legal document, dated 1439, by which it is proved that Gutenberg, being engaged "in a wonderful and unknown art," admitted certain persons into partnership, one of whom dying, his brother claimed to be admitted as his successor; and on Gutenberg's refusal, they brought an action against him as principal partner. From the evidence produced in the trial, it was proved that one of the witnesses had been instructed by Gutenberg to "take the *stücke* (pages) from the presses, and, by removing two screws, thoroughly separate them from one another, so that no man may know what it is." From this curious document (says the latest investigator of the subject) may be learnt that separate types were used; for if they were block, arranged so as to print four pages (as stated in the evidence), how could they be so pulled to pieces that no one should know what they were, or how could the abstraction of two screws cause them to fall to pieces? We are here reminded that within comparatively few years screws have been substituted for quoins, or



GUTENBERG, THE INVENTOR OF PRINTING

wedges, in locking up the type in the chases, or iron frames; which may be a revival of Gutenberg's screw method of four hundred years since.

It seems that some sort of presses were now used, and the transfers no longer taken by a burnisher or roller; and lastly, that the art was still a great secret at the time when Koster was at the point of death. Hence it is manifest that the ingenuity of Gutenberg had made a vast advance from the rude methods of the time, and had in fact invented a new and hitherto unknown art.

All this took place at Strasburg, where Gutenberg resided many years; but it did not lead to any practical result, and the first book was printed at Mentz, near which the inventor was born. Thither Gutenberg returned about the year 1450, with all his materials. His former partnership had expired, and at Mentz he associated himself with John Fust, a wealthy goldsmith and citizen, who, upon agreement of being taught the secrets of the art, and admitted into the participation of the profits, advanced the necessary funds, 2,020 florins. The new partnership then hired a house called *Zum Jungen*, and took into their employ Peter Schœffer and others. A law suit arose between the partners in 1455; and from a document in existence we learn that, having expended the whole of his considerable private fortune in his experiments, Gutenberg had mortgaged his printing materials to Fust, which is proved by the initial letters used by Gutenberg and his partners in printing works between 1450 and 1455, being likewise used by Fust and Schœffer in the Psalter of 1457 and 1459. Gutenberg did not, however, abandon the unprofitable pursuit, but starting anew at Mentz, carried on the business for ten years; but in 1465, on becoming one of the band of gentleman pensioners of the Elector Adolphus of Nassau, "he finally abandoned the pursuit of an art, which, though it caused him infinite trouble and vexation, has been more effectual in preserving his name and the memory of his acts than all the warlike deeds and great achievements of his renowned master and all his house" (Hansard) Gutenberg died on the 24th day of February, 1468. His printing office and materials were eventually sold to Nicholas

Bechtermunze of Elfield, whose works are greatly sought after by the curious, as they afford much proof, by collation, of the genuineness of the works attributed to his great predecessor.

It is hard to apportion the share of honor to which each of the partners—Gutenberg, Fust, and Schœffer—is entitled in advancing their art. Gutenberg would readily suggest a new and expeditious method of manufacturing types; the practical skill of Fust as a worker in metals, and his large pecuniary resources, would provide the necessary appliances; and the entire conception and execution of the casting of type is given to Schœffer. The only evidence shows that the partners had for some time taken casts of types in molds of plaster; for the types of Gutenberg's earlier efforts, both at Strasburg and at Mentz, were cut out of single pieces of wood or metal with infinite labor and imperfection. Schœffer has therefore an undoubted claim to be considered as one of the three inventors of printing; for it was he who first suggested the cutting of punches, whereby beautiful forms could be stamped upon the matrix, and the highest sharpness and finish given to the face. Lambinet, who thinks "the essence of the art of printing is in the engraved punch," naturally gives the chief credit to Schœffer; this is not the generally received opinion; but he is entitled to a place on the right hand of Gutenberg. It should be noted, that there is no book known which bears the conjoint names of Gutenberg, Fust, and Schœffer, nor any which has the imprint of Gutenberg alone; but there are several books which, from internal evidence, are unanimously attributed by the *literati* of all parties and opinions to Gutenberg's press.

It is curious to observe that war was the means of quickening the growth and extension of printing. In 1462, the storming of Mentz dispersed the workmen, and gave the secret to the world. In 1465, it appeared in Italy; in 1469, in France; in 1474, Caxton brought it to England; and in 1477, it was introduced into Spain.

It is generally believed that William Caxton was born in the Weald of Kent. About 1412 he was put apprentice to a mercer or merchant of London, became a traveling agent or factor in the Low Countries, and there bought manuscripts

and books, with other merchandise. He there also learned the new art of printing; and, securing one of Fust and Schœffer's fugitive workmen from Mentz, he established a printing office at Cologne, and there printed the French original and his own translation of the *Recuyell of the Historyes of Troy*. He afterward transferred his materials to England, and brought over with him Wynkyn de Worde, who probably was the first superintendent of Caxton's printing establishment. He set up his first press at Westminster, perhaps in one of the chapels attached to the Abbey, and certainly under the protection of the abbot; and he there produced the first book printed in England, *The Game of Chesse*, completed on the last day of March, 1474. His "capital work" was a *Book of the Noble Historyes of Kyng Arthur*, the most beautiful production of his press. He died in 1491, being about fourscore years of age. His industry and devotedness are recorded in the fact that he finished his translation of the *Vitæ Patrum*, from French into English, on the last day of his life.

Caxton was buried in the old church of St. Margaret, built in the reign of Edward I., and of which few traces remain. The parish books contain an entry of the expense "for iiij torches" and "the belle" at the old printer's "bureying"; and the same books record the churchwardens' selling for 6s. 8d. one of the books bequeathed to the church by Caxton! In the chancel a tablet to his memory was raised in 1820 by the Roxburghe Club.

A few words about the first presses. Gutenberg is thought to have felt the want of a machine of sufficient power to take the impressions of the types or blocks which he employed; nor is it supposed that, with cutting type, forming screws, making and inventing ink, he could have had time to construct a press, even had he possessed the requisite mechanical skill. His junction with Fust and Schœffer is thought to have supplied the defect.

The earliest form of printing press very closely resembled the common screw press, as the cheese or napkin press, with some contrivance for running the form of types, when inked under the pressure (obtained from the screw by means of a

lever inserted into the spindle), and back again when the pressure is made. The presses used in the office of Fust and Schœffer are believed to have differed in no essential form from the above, until improved in the details by Blew, a printer of Amsterdam, in 1620. Other improvements were from time to time introduced; but they were all superseded about the commencement of the present century, when the old wooden press gave way to Earl Stanhope's invention of the iron press which bears his name. Its novelty consisted in an improved application of the power to the spindle and screw, whereby it was greatly increased. Lord Stanhope also made some improvements in the process of stereotyping, and in the construction of locks for canals; he invented an ingenious machine for performing arithmetical operations; during a great part of his life he studied the action of the electric fluid; and in 1779 he made public his theory of what is called "the returning stroke of lightning." Lord Stanhope bequeathed £500 to the Royal Society, of which he had been a fellow fifty-one years.

The principle of the Stanhope press has been followed out by several subsequent inventors; and improvements of mechanical detail introduced, tending to the economy of time and labor, and to precision of workmanship. The printing press, however, proved inadequate to a rate of production equal to the demand; and as early as 1790, even before the Stanhope press was generally known, Mr. W. Nicholson patented a printing machine, of which the chief points were the following: "The type, being rubbed or scraped narrower towards the bottom, was to be fixed upon a cylinder, in order, as it were, to radiate from the centre of it. This cylinder, with its type, was to revolve in gear with another cylinder covered with soft leather (the impression cylinder), and the type received its ink from another cylinder, to which the inking apparatus was applied. The paper was impressed by passing between the type and impression cylinders" (Hansard). Such was the first printing machine; it was never brought into use, although most of Nicholson's plans were, when modified, adopted by after-constructors.

König, a German, conceived nearly the same idea; and

meeting with the encouragement in England which he failed to receive on the Continent, constructed a printing machine for Mr. Walter; and on November 28, 1814, the readers of the "Times" were informed that they were then, for the first time, reading a newspaper printed by machinery driven by steam power, and working at the rate of 1,100 impressions per hour. In this machine the ordinary type was used, and laid upon a flat surface, the impression being given by the form passing under a cylinder of great size.

The later improvements in printing cannot be adequately described in brief. Every one knows something of the wonderful typesetting machines by which one operator, sitting before what looks like an enlarged typewriter, does the labor of five hand compositors. By tapping the keys he causes molten metal to come out in the form of a line of solid type, ready to be inked and printed from. Hence the name Linotype. One of the most recent developments of this principle is the Lanston Monotype machine, which is at work producing magazines and books. The inventor describes it thus:

"A perfect typesetting machine should take the place of the hand compositor, setting the type letter by letter in proper order at a maximum speed and with a minimum chance of error. The Lanston Monotype machine solves this problem marvelously. To one who has seen the slow work of hand typesetting as the compositor builds up a long column of metal piece by piece, letter by letter, picking up each character from its allotted space in the font, and placing it in its proper order and position, and then realizes that much of the printed matter he sees is so produced, the wonder is how anything is ever accomplished.

In a quarto page of good-sized type there are about 7,000 separate pieces (not including spaces) of type, which, if set by hand, would have to be taken one by one and placed in the compositor's "stick," then when the line is nearly set it would have to be spaced out or justified to fill out the line exactly. Then when the compositor's "stick" is full, or two and a half inches have been set, the type has to be taken out and placed in a long channel or "galley." Each of these three operations

requires considerable time and close application, and with each change there is the possibility of error. It is a long, expensive process—a process in which the human equation is far too prominent. These three steps of hand composition, slow, expensive, open to many chances of mistake, have been covered at one stride at five times the speed, at one-third the cost, and much more accurately by the Monotype Machine.

A man sits at a keyboard, much like a typewriter in appearance, containing every character in common use (two hundred and twenty-five in all), and at a speed only limited by his dexterity he plays on the keys exactly as a typewriter works his machine. This is the sum total of human effort expended. The machine does all the rest of the work; furnishes the brains, and delivers the product in clean, shining new type, each piece perfect, each in its place, each line of exactly the right length, and each space between the words mathematically equal—absolutely “justified.” It is practically hand composition with the human possibility of error, of weariness, of inattention, of ignorance, eliminated, all accomplished with a celerity that is astonishing.

The Lanston is a typesetting machine as well as typesetter. It casts the type (individual characters) it sets, perfect in face and body, capable of being used in hand composition or put to press directly from the machine and printed from. As each piece of type is separate, alterations are easily made—the corrected type, which the machine itself casts, is simply substituted for the defective matter, as in hand composition.

The machine is composed of two parts, the keyboard and the casting-setting machine. The keyboard part may be placed wherever convenient, away from noise or anything that is likely to distract or interrupt the operator, and the perforated roll of paper produced by it (which governs the setting machine) may be taken away as fast as it is finished. In the casting-setting machine is located the brains. The five-inch roll of paper perforated by the keyboard machine (a hole for every letter) gives the signal by means of compressed air to the mechanism that puts the matrix (or type mould) in position and casts the type letter by letter, each character following the proper sequence

as marked by the perforations of the paper ribbon. By means of an indicator scale on the keyboard the operator is informed how many spaces there are between the words of the line and the remaining space to be filled out to make the line the proper width. This information is marked on the paper ribbon by the pressure of two keys, and when the ribbon is transferred to the casting machine these space perforations so govern the casting that the line of type delivered at the "galley" complete shall be exactly the proper length and the spaces between the words be equal to the infinitesimal fraction of an inch.

LABOR-SAVING MACHINERY

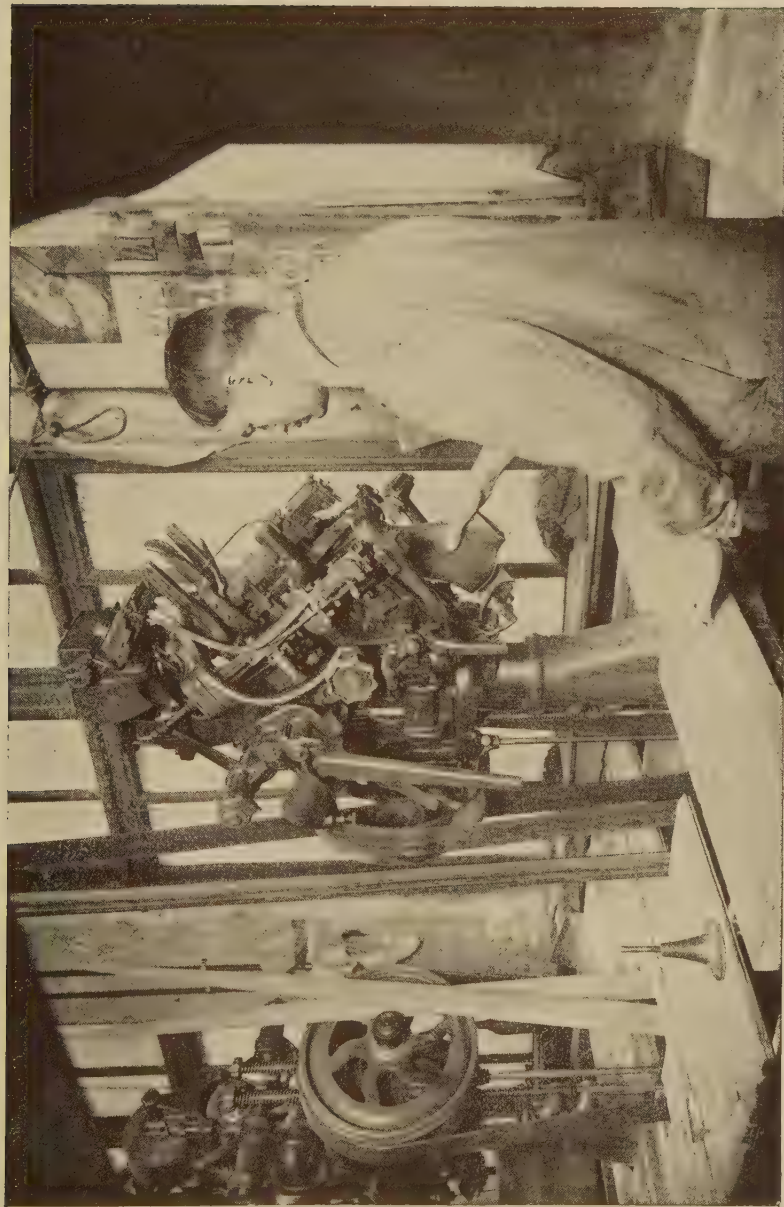
Shoemaking Machines

By EARL MAYO

THE commonest things are the greatest mysteries. We search for the unknown and surprising to the uttermost parts of the earth, when, if we were wise enough to look there, we might find both under our very noses, or under our very feet.

To make good this statement in its most literal sense, take the shoe as an example. Certainly nothing is more common, more familiar, or more ubiquitous than the shoe. To provide the American people with footwear requires close to half a million pairs per day. There is no object more familiar to us all than a shoe, and yet of the mystery of its creation, of the marvelous ingenuity applied in its construction, not one man out of a hundred picked at random from the street could tell anything.

But there is no mystery about the making of a shoe, you say; and if pressed to the point, you may succeed in describing with fair exactitude the tedious operations of the leathern-aproned cobbler whom you used to pass each morning on your way to school, slowly pounding the leather to the shape of his last, punching with his awl, drawing his waxed ends through and through the leather, trimming with his queer-shaped knives. You have an idea that the methods of the old cobbler have been improved upon somewhat, but you do not realize that, measured by the march of industrial progress, he is as distant as the middle ages. It took the cobbler three days to make a pair of shoes. I have just visited a factory in Boston where 8,000 pairs of shoes are turned out every day by a force of



SHOE-MAKING MACHINE.

2,400 operators. This means three and one-half pairs for every man, woman, and child employed in the place. And yet not one of them possesses the skill of the vanished cobbler; not one of them could make a pair of shoes unaided by his fellows, and not more than two-thirds of them are employed directly in making shoes. The difference in the rate of production between the new workman and the old represents the share that machinery has come to play in the sphere of production. The results of the cobbler's experienced efforts have been multiplied by fifteen, and the multiplier is the complex machinery that inventive genius has supplied to do the work of human hands and brains—machines that almost think.

While these machines have increased enormously the possibilities of production, they have also complicated the methods by which these results are attained. It doubtless will surprise the average reader to be told that the shoes on his feet have passed through fully a hundred operations in their progress from the sheet of leather to the finished product; that there are fully this number of separate parts in every pair of shoes, and that some seventy or eighty hands have helped to shape them into what they are. But if he could view the transformation as it takes place thousands of times each day beneath the roof of every great shoe manufactory, if he could watch the leather assuming useful form as one intelligent piece of mechanism after another contributes its part toward the common result, he would be more astonished than he can be by any mere description.

To make thousands of highly specialized workmen and thousands of highly specialized machines work together in an economical, orderly, and profitable manner requires a thorough systematization. Thus every great shoe manufactory is so arranged that the raw material, starting at one end of the factory beneath the roof as a sheet of leather, emerges on the ground floor as a completed shoe ready to wear. To view the evolution of the shoe, therefore, let us mount together to the top of a big factory devoted to turning out a medium grade of shoes—shoes that can be purchased for three dollars or three dollars and a half per pair.

At the outset we encounter a mechanical wonder, a machine that knows arithmetic far better than we do, and that can perform instantaneously and easily a task that even a highly intelligent man could execute only slowly and tediously.

The leather comes into the factory in the form of pelts already tanned and prepared. These skins retain the same shape as when stripped from the calf or kid that they originally covered. Consequently they are irregular in form, having projections at the corners representing the part of the hide that came off the animal's legs. This leather is purchased by the square foot, and each pelt bears a mark indicating the number of square feet it contains. To measure each skin by the ordinary methods would be an impossible task, and yet, in a factory where thousands of them are used daily, it is in the highest degree important for the manufacturer to know whether or not he is receiving full measure.

To meet this requirement a very skillful machine has been devised. It is a primitive affair in appearance, consisting of a broad table, close to the surface of which are set a number of wheels placed close together on a horizontal axle on which they can revolve freely. Above the wheels, attached to the framework of the machine, are a series of balances arranged exactly as in an old-fashioned pair of scales, and surmounting the whole thing is a dial carrying an indicator marked off by figures, with spaces to show halves and quarters. Some odd-fangled weighing machine, one would say at first glance, but it is in reality a measuring machine instead.

Forming a part of each wheel and projecting from its side is a raised portion forming a segment of the circle represented by the wheel itself. Attached to one end of the arc of each segment is a wire chain extending over the pulleys carried on the arms of the balance. If the wheels are set in motion, their movement pulls downward on the chains, which in turn exert a pull on the arms of the balance; and the latter, being connected with the indicator of the dial, deflect it.

The space between the table and the set of wheels is just about wide enough for a sheet of paper to pass through. Set in the table to come exactly flush with its surface is a pair of

rolls which are set in motion whenever the machine is connected with the driving shaft that runs all the machinery in the room. If a pelt is placed on the table, these rolls carry it forward; it comes in contact with some of the set of wheels; the wheels turn, and their pull moves the indicator forward across the face of the dial.

Now the beauty of this mechanism is that its pulleys are so adjusted, in accordance with laws which every schoolboy learns in his study of physics, that the deflection of the indicator marks on the dial exactly the number of square feet in the surface of the side of leather that passes beneath the wheels. It matters not what the shape of the pelt may be, square, circular, or irregular, each part of it passes under some of the wheels on the axle, and causes them to move while it is passing beneath them and only them. Only a few seconds are required in the process, and the area of the leather is measured exactly to the fraction of a foot. Of course not all the pelts that come into the factory are measured; from each case that is opened a few are tested merely to verify the figures of the seller. If any discrepancy is found, the deficient pelts are not accepted.

The first step in the actual construction of the shoe is the cutting out of the leather and linings by patterns. There are separate patterns for each part, for each width and size, for each style; separate patterns for right and left shoes. A great amount of skill and art goes into the making of these patterns, and of the lasts on which the embryo shoes are placed later on in their careers. The chief pattern maker of a big concern frequently receives a salary of \$5,000 or thereabouts. Many of the manufacturers buy their patterns and lasts ready made, and the manufacture of these is really a separate branch of the business.

In the cutting department we again confront the work of labor-saving machinery. A machine with a heavy beam, working exactly like a pile-driver, is cutting out linings, sending the sharp-edged steel form through thirty-two thicknesses of cloth at each blow. Rather more rapid than cutting out each lining with a pair of shears, is it not? But the machine is of

the powerful, lumbering sort that lacks intelligence, and does not interest us particularly.

One point we need to observe here in the cutting-room in order to understand how it is that dozens of different parts entering into the construction of the shoe are kept from becoming hopelessly scattered. Attached to each bundle of parts as it is cut out is a long sheet covered with letters and figures which form the specifications for each pair of shoes, or rather for the number of pairs that are to be made from the one model at one time. The sheet is perforated so that it may be divided into three or four sections, but each section contains the same stamped number. Some part of this tag is attached to each of the parts of the shoe, so that, however widely separated the parts may become in their progress through the factory, they are brought together again at the proper time and place. The specification sheet serves another useful purpose. As each sheet contains a separate number, which is also stamped on the inside of the shoe, it is possible, by referring to this number, to trace the history of every pair of shoes back, even to the cutting-room, and through the hands of every operator who had a part in its production.

The processes of sewing together the different parts forming the upper and lining of the shoe and the making of button-holes call for no particular description. They go on in what are known as the stitching-rooms, where hundreds of women, ranged before hundreds of sewing machines, are busily at work. Some of these machines present variations on familiar models, and perform tasks that are beyond the range of ordinary sewing machines.

By far the cleverest piece of mechanism in this department is the apparatus for stamping holes and putting in the eyelets through which the laces are to run. This machine has an arm extending out like the arm of a sewing machine. Along this arm is a grooved passage way leading from a hopper above the machine. The hopper is filled with blank forms of eyelets which are swept into the groove by a revolving brush. The perpendicular part of the machine's long arm is governed in its motion by a drive-wheel, and works like the needle-holder in a

sewing machine, except that, instead of a continuous motion, it is driven downward once for each revolution of the wheel.

A second arm, extending alongside and operated in the same way, carries a punch. When the shoe is placed in position and the machine is set in motion, the punch is driven downward, cutting a circular hole through the leather. At the next movement the shoe is carried forward, an eyelet fed out of the groove is caught by the point of the miniature pile-driver in its descent, is carried into the hole prepared for it, and neatly flattened out by the force of the blow, so that it is firmly pinned in position. By merely pressing a foot lever, the arm carrying the punching apparatus can be moved forward or backward, thus regulating the distance between the holes.

One of these machines will insert the eyelets in a case of shoes containing thirty-six pairs in fifteen minutes. This means something like eighty finished eyelets to the minute. The machine does in a quarter of an hour an amount of work that a skilled artisan could not accomplish in a day, and does it with a precision and regularity that the human workman could not equal. And the machine is operated by a young girl.

At this stage in its progress the various pieces forming the upper part of the shoe have been joined together. All the work has been done by machinery except the cutting out of certain parts from the patterns. Meanwhile, in another part of the factory the materials for the sole have been shaping. The thick outer covering and the thin inside part have been stamped out by forms placed beneath heavy beams operated as the one that we observed in the act of cutting out the linings. The inner sole has been shaped to the form that it occupies in the finished shoe by means of a heavy moulder operated by hydraulic power; at the same time a ridge has been raised up around the outer edge, to which a covering of canvas is attached by a stitching machine, thus adding greatly to its holding power.

The final step before the junction of the upper shoe and the sole is the sewing on of the welt, a strip of strong leather which serves to join the soft upper to the less flexible sole.

The welt is attached by means of a sewing machine directly after the shoe has gone through the process of lasting.

Here, at least, you will say, is a task before which machinery is helpless. To give a shoe the qualities requisite to a good fit, to keep it from drawing here and wrinkling there, it is necessary that the leather be drawn carefully over the wooden last which is placed inside the shoe, and fastened there with tacks to await the process of sewing. To become a competent laster requires skill and long experience, and the men who perform this work are always among the best paid in the factory. In many establishments the lasting is done by hand still, but there is a machine which will do the work and do it well, and this machine is utilized to a considerable extent in the making of the cheaper grade of shoes. It was named derisively the "nigger" laster by the workmen, because of the fact that its inventor was a mulatto; but no very long inspection is required to convince one of the fact that the machine is one entitled to respect.

A steel thumb and finger, working on a steel arm, grip the edge of the leather, and with the sideways pull characteristic of the hand laster bring the leather lightly over the edge of the last. At the end of the arm's pull, and just before the spring controlling the thumb and finger is released, a second arm descends with a sharp blow. This second arm is an automatic hammer. Short tacks are automatically fed along a narrow groove from a small hopper to a position directly beneath the hammer. The beauty of the apparatus is that it drives the nail only half way into the last, so that it may be pulled out easily when the sole is sewed on; a small circular guard below the hammer prevents the nail from being driven in for its full length. This mechanical laster works much more rapidly than any hand workman is capable of doing, and it performs a task that requires, in the case of the human workman, a combination of good judgment with mechanical exactitude.

The lasting is merely a preparatory step to the sewing of the shoe, which is done by another species of the remarkable sewing machines that are so much in evidence throughout the factory. The entire welt is sewed on in a fraction of a second,

instead of the half hour occupied by the laborious method of the old-time hand operator. A cutting machine, following the sewer, neatly trims off the edges.

The shoe is now ready to enter upon another stage of its construction—the affixing of the outer sole and heel; and we notice the fact that up to this point the light shoes for women have been put together inside out, although this is not the case with men's footwear.

The space between the inner and outer soles is filled with a substance the composition of which varies according to the notion of the manufacturer or the quality of the shoe. The most common is a mixture of ground cork and cement, which is useful in resisting damp, and at the same time assists the wearing quality of the shoe. When this has been done, the shoe is placed on a form beneath a heavy weight. The outer sole is covered with rubber cement laid in position, and pressed upon the shoe. The cement holds it in place temporarily until it can be sewed together by a machine that drives both needle and thread right through the heavy sole and affixes it firmly to the welt.

Next comes into play a very simple but extremely ingenious machine. The shoe is placed on another form, and a heavy roller, carrying a pressure of two tons, is run over the sole, forcing it down compactly upon the upper, and giving it the neatly rounded and finished appearance which the bottom of a new shoe presents. The arm carrying this roller moves backward and forward, and is so geared as to have also a rocking motion. Consequently the roller passes over every inch of the shoe's bottom surface, and its movements as it runs forward and backward, tilting from side to side, are remarkably humanlike, and suggest the presence of a brain hidden away somewhere in the machine and directing its operations.

When the sole has been put in place, the heel is affixed, and this is done by a machine suggestively named "the lightning nailer."

The various layers of leather comprising the heel have been pasted together in another part of the factory, or perhaps in another factory, for many of the shoemakers buy their heels

ready made. There remains only to fasten the heel to the shoe and to affix the bottom or outside heel-top, which is always put on separately. To do this is the work of the lightning nailer.

The machine is fed from a hopper into which the nails are poured and from which they are shaken down grooved inclines to fall into a form at the bottom. The form is exactly the shape of a shoe heel, and in it the nails are held upright in the position in which they are to be driven into the shoe. The heel is placed in position; the arm carrying the form, filled with upright nails, is carried horizontally about just above the heel; the valve that has held the nails from slipping out has been thrown aside by the release of a catch; a hammer descends and drives all the nails home at one blow, and contact with the iron form on which the shoe is placed clinches them on the inside. Along comes another arm, carrying the outside heel-top, over which a brushful of glue has been passed, and another smart blow fastens this in position, covering up the heads of the nails which hold the heel in place. Another machine, similar in operation, drives the row of nails which you may observe running along the outer edge of the heel of your shoe. These latter help hold the heel together to some extent, but they are put in chiefly for appearance' sake.

As soon as the outer edges of the sole and heel have been trimmed off smoothly by swiftly revolving circular knives, the shoe is practically complete. It is cleaned by revolving brushes; the sole is burnished on sandpaper and emery wheels; it is waxed by being held against a revolving wax-mould; the name and trademark of the maker is impressed by a mechanical stamp; the laces are inserted by girl operators; the shoe passes through the hands of an inspector, and thence it goes to the packing room, whence it emerges with thousands of others, packed in a neat cardboard box, ready for sale.

This rough description covers only the essential steps in the building of a shoe from a flat strip of leather into a form that will fit the human foot. There are dozens of minor operations, designed to add to the beauty or finish of the shoes, that have not been touched upon, and there are clever machines that perform nearly all these operations.

For example, if you look at the sole of a new shoe you will notice that the threads by which it is sewn do not show at all. Before the sole is sewed to the welt it receives the attention of a machine carrying a swiftly revolving, sharp little wheel that runs around its edge, turning up a thin layer of leather. After the sole is fastened on, this layer is turned down and pressed firmly by the heavy roller mentioned above. Similarly there is the "foxing" machine, which stamps out the rows of holes often seen along the edge of a box-tip or a vamp, and which give the shoe a finer appearance in the opinion of many buyers.

Another trick of the clumsy machinery that supplies us with footwear imitates the appearance of a hand-sewed sole. If you look on the top surface of the extension sole of a fashionable shoe you will notice a series of little grooves or cuts extending outward and separating the stitches by which the sole and welt are fastened together. The custom shoemaker cuts these little depressions so that his stitches will sink in even with the surface, and thus make his work less clumsy in appearance. The machine sewer draws these stitches as tight as it is possible for them to be, but, notwithstanding that they serve no practical purpose, the little grooves are added to improve the appearance of the shoe and to counterfeit the effect of hand-sewing.

If you watched the old cobbler carefully in the boyhood or girlhood days in which your ideas of shoemaking were formed, you may have noticed that whenever he sewed two pieces of leather together, he was accustomed to pound down the seam with his hammer to make it as flat as possible. The same thing is done in the modern factory, except that the pounding is done by an automatic hammer that strikes two hundred blows to the minute, and does the work in one-fiftieth of the time required by the man of the awl and leathern apron. In fact, inventive genius has succeeded in turning out machinery that performs rapidly and efficiently practically every operation that the most painstaking custom shoemaker of a generation ago put into his work.

LIGHT AND ITS USES

New Light on Light, or Revelations of Spectrum Analysis

By ALFRED RUSSEL WALLACE

HOW long ago it is since the use of fire, and some mode of producing it, enabled man to make the first advance toward civilization, we have no means of determining. As a matter of fact, the method of producing fire by friction is that most common among savages in all parts of the world; and since it requires only materials that are almost everywhere at hand, it descended even to some civilized peoples.

The more convenient method of striking a light by the use of flint, steel, and tinder, probably originated after iron was first made, and soon became adopted by all civilized people, and by many savages who possessed iron; and this method continued in use from the times of prehistoric man through all the ages of barbarism and civilization down to a century ago, and the process underwent hardly any improvement during that long period. One of the most vivid recollections of my childhood is of seeing the cook make tinder in the evening by burning old linen rags, and in the morning, with flint and steel obtaining the spark which, by careful blowing, spread sufficiently to ignite the thin brimstone match from which a candle was lit and fire secured for the day. The process was, however, sometimes, a tedious one, and if the tinder had accidentally got damp, or if the flint were worn out, after repeated failures a light had to be obtained from a neighbor. At that time there were few savages in any part of the world but could obtain fire as easily as the most civilized of mankind.

At length, after the use of these rude methods for many thousand years, a great discovery was made which revolutionized the process of fire-getting. The properties of phosphorus were known to the alchemists, and it is strange that its ready ignition by friction was not made use of to obtain fire at a much earlier period. It was, however, both an expensive and a dangerous material, and though about a hundred years ago it began to be made cheaply from bones, it was not used in the earliest friction matches. These were invented in 1827, or a little earlier, by John Walker, a chemist and druggist of Stockton-on-Tees, and consisted of wood splints, dipped in chlorate of potash and sulphur mixed with gum, which ignited when rubbed on sandpaper. Two years later the late Sir Isaac Holden invented a similar match. About 1834, phosphorus began to be used with the other materials to cause more easy ignition, and by 1840 these matches became so cheap as to come into general use in place of the old flint and steel. They have since spread to every part of the world, and their production constitutes one of the large manufacturing industries of England, Sweden, and many other countries.

Coming now to the use of fire as a light-giver, we find that an even greater change has taken place in our time. The first illuminants were probably torches made of resinous woods, which will give a flame for a considerable time. Then the resin exuding from many kinds of trees would be collected and applied to sticks or twigs, or to some fibrous materials tied up in bundles, such as are still used by many savage peoples, and were used in the old baronial halls. For out-door lights torches were used almost down to our times, an indication of which is seen in the iron torch extinguishers at the doors of many of the older West End houses; while, before the introduction of gas, link-boys were as common in the streets as match-sellers are now. Then came lamps, formed of small clay cups, holding some melted animal fat and a fibrous wick; and, somewhat later, rush-lights and candles. Still later, vegetable oils were used for lamps and wax candles; but the three modes of obtaining illumination for domestic purposes remained entirely unchanged in principle, and very little improved, throughout

the whole period of history down to the end of the eighteenth century. The Greek and Roman lamps, though in beautiful receptacles of bronze or silver, were exactly the same in principle as those of the lowest savage, and hardly better in light-giving power; and though various improvements in form were introduced, the first really important advance was made by the Argand burner. This introduced a current of air into the center of the flame as well as outside it, and, by means of a glass chimney, a regular supply of air was kept up, and a steady light produced. Although the invention was made at the end of the last century, the lamps were not sufficiently improved and cheapened to come into use till about 1830; and from that time onward many other improvements were made, chiefly dependent on the use of the cheap mineral oils, rendering lamps so inexpensive, and producing so good a light, that they are now found in the poorest cottages.

The only important improvement in candles is due to the use of paraffine fats instead of tallow, and of flat plaited wicks which are consumed by the flame. In my boyhood, the now extinct "snuffers" were in universal use, from the common rough iron article in the kitchen to elaborate polished steel spring-snuffers of various makes for the parlor, with pretty trays for them to stand in. Candles are still very largely used, being more portable and safer than most of the paraffine oil lamps. Even our lighthouses used only candles down to the early part of the present century.

A far more important and more radical change in our modes of illumination was the introduction of gas lighting. A few houses and factories were lighted with gas at the very end of the last century, but its first application to out-door or general purposes was in 1813, when Westminster Bridge was illuminated by it, and so successfully that its use rapidly spread to every town in the kingdom, for lighting private houses as well as streets and public buildings. When it was first proposed to light London with gas, Sir Humphrey Davy is said to have declared it to be impracticable, both on account of the enormous size of the needful gas-holders, and the great danger of explosions. These difficulties have, however, been overcome, as

was the supposed insuperable difficulty of carrying sufficient coal in the case of steamships crossing the Atlantic, the impossibilities of one generation becoming the realities of the next.

Still more recent, and more completely new in principle, is the electric light, which has already attained a considerable extension for public and private illumination, while it is applicable to many purposes unattainable by other kinds of light. Small incandescent lamps are now used for examinations of the larynx and in dentistry, and a lamp has even been introduced into the stomach by which the condition of that organ can be examined. For this last purpose numerous ingenious arrangements have to be made to prevent possible injury, and by means of prisms at the bends of the tube the operator can inspect the interior of the organ under a brilliant light. Other internal organs have been explored in a similar manner, and many new applications in this direction will no doubt be made. In illuminating submarine boats and exploring the interiors of sunken vessels it does what could hardly be effected by any other means.

The improvements in the mode of production of light for common use are sufficiently new and remarkable to distinguish this century from all the ages that preceded it, but they sink into insignificance when compared with the discoveries which have been made as to the nature of light itself, its effects on various kinds of matter leading to the art of photography, and the complex nature of the solar spectrum leading to spectrum analysis. This group of investigations alone is sufficient to distinguish the present century as an epoch of the most marvelous scientific discovery.

Although Huygens put forward the wave theory of light more than two hundred years ago, it was not accepted, or seriously studied, till the beginning of the present century, when it was revived by Thomas Young, and was shown by himself, by Fresnel, and other mathematicians, to explain all the phenomena of refraction, double refraction, polarization, diffraction, and interference, some of which were inexplicable to the Newtonian theory of the emission of material particles, which had previously been almost universally accepted. The complete establishment of the undulatory theory of light is a fact of the high-

est importance, and will take a very high place among the purely scientific discoveries of the century.

From a more practical point of view, however, nothing can surpass in interest and importance the discovery and continuous improvement of the photographic art, which has now reached such a development that there is hardly any science or any branch of intellectual study that is not indebted to it. A brief sketch of its origin and progress will therefore not be uninteresting.

The fact that certain salts of silver were darkened by exposure to sunlight was known to the alchemists in the sixteenth century, and this observation forms the rudiment from which the whole art has been developed. The application of this fact to the production of pictures belongs, however, wholly to our own time. In the year 1802, Wedgewood described a mode of copying paintings on glass by exposure to light, but neither he nor Sir Humphry Davy could find any means of rendering the copies permanent. This was first effected in 1814 by M. Niepce of Châlons, but no important results were obtained till 1839, when Daguerre perfected the beautiful process known as the daguerrotype. Permanent portraits were taken by him on silvered plates, and they were so delicate and beautiful that probably nothing in modern photography can surpass them. For several years they were the only portraits taken by the agency of light, but they were very costly, and were therefore completely superseded when cheaper methods were discovered.

About the same time a method was found for photographing leaves, lace, and other semi-transparent objects on paper, and rendering them permanent, but this was of comparatively little value. In the year 1850, the far superior collodion-film on glass was perfected, and negatives were taken in a camera-obscura, which, when placed on black velvet, or when coated with a black composition, produced pictures almost as perfect and beautiful as the daguerrotype itself, and at much less cost. Soon afterward positives were printed from the transparent negatives on suitably prepared paper, and thus was initiated the process, which, with endless modifications and improvements, is still in use. The main advance has been in the in-

creased sensitiveness of the photographic plates, so that, first, moving crowds, then breaking waves, running horses, and other quickly moving objects were taken, while now a bullet fired from a rifle can be photographed in the air.

With such marvelous powers, photography has come to the aid of the arts and sciences in ways which would have been perfectly inconceivable to our most learned men of a century ago. It furnishes the meteorologist, the physicist, and the biologist with self-registering instruments of extreme delicacy, and enables them to preserve accurate records of the most fleeting natural phenomena. By means of successive photographs at short intervals of time, we are able to study the motions of the wings of birds, and thus learn something of the mechanism of flight; while even the instantaneous lightning-flash can be depicted, and we thus learn, for the first time, the exact nature of its path.

Perhaps the most marvelous of all its achievements is in the field of astronomy. Every increase in the size and power of the telescope has revealed to us ever more and more stars in every part of the heavens; but, by the aid of photography, stars are shown which no telescope that has been, or that probably ever will be constructed, can render visible to the human eye. For by exposing the photographic plate in the focus of the object glass for some hours, almost infinitely faint stars impress their image, and the modern photographic star maps show us a surface densely packed with white points that seem almost as countless as the sands of the seashore. Yet every one of these points represents a star in its true relative position to the visible stars nearest to it, and thus gives at one operation an amount of accurate detail which could hardly be equaled by the labor of an astronomer for months or years—even if he could render all these stars visible, which, as we have seen, he cannot do. A photographic survey of the heavens is now in progress on one uniform system, which, when completed, will form a standard for future astronomers, and thus give to our successors some definite knowledge of the structure, and, perhaps, of the extent of the stellar universe.

It has long been the dream of photographers to discover

some mode of obtaining pictures which shall reproduce all the colors of nature without the intervention of the artist's manipulation. This was seen to be exceedingly difficult, if not impossible, because the chemical action of colored light has no power to produce pigments of the same color as the light itself, without which a photograph in natural colors would seem to be impossible. Nevertheless, the problem has been solved, but in a totally different manner; that is, by the principle of "interference," instead of by that of chemical action.

This principle was discovered by Newton, and is exemplified in the colors of the soap bubble, and in those of mother-of-pearl and other iridescent objects. It depends on the fact that the differently colored rays are of different wave lengths, and the waves reflected from two surfaces half a wave length apart neutralize each other and leave the remainder of the light colored. If, therefore, each differently colored ray of light can be made to produce a corresponding minute wave structure in a photographic film, then each part of the film will reflect only light of that particular wave length, and therefore of that particular color that produced it. This has actually been done by Professor Lippmann, of Paris, who published his method in 1891; and in a lecture before the Royal Society in April, 1896, he fully described it and exhibited many beautiful specimens.

The principle is the same for the light waves as that of the telephone for sound waves. The voice sets up vibrations in the transmitting diaphragm, which, by means of an electric current, are so exactly reproduced in the receiving diaphragm as to give out the same succession of sounds. An even more striking and, perhaps, closer analogy is that of the phonograph, where the vibrations of the diaphragm are permanently registered on a wax cylinder, which, at any future time, can be made to set up the same vibrations of the air, and thus reproduce the same succession of sounds, whether words or musical notes. So, the rays of every color and tint that fall upon the plate throw the deposited silver within the film into minute strata which permanently reflect light of the very same wave length, and therefore of the very same color as that which produced them.

The effects are said to be most beautiful, the only fault being that the colors are more brilliant than in nature, just as they are when viewed in the camera itself. This, however, may perhaps be remedied (if it requires remedying) by the use of a slightly opaque varnish. The comparatively little attention that has been given to this beautiful and scientifically perfect process is no doubt due to the fact that it is rather expensive, and that the pictures cannot, at present, be multiplied rapidly. But for that very reason it ought to be especially attractive to amateurs, who would have the pleasure of obtaining exquisite pictures which will not become commonplace by indefinite reproduction.

The brief sketch of the rise and progress of photography now given illustrates the same fact which we have already dwelt upon in the case of other discoveries. This beautiful and wonderful art, which already plays an important part in the daily life and enjoyment of all civilized people, and which has extended the bounds of human knowledge into the remotest depths of the starry universe, is not an improvement of, or development from, anything that went before it, but is a totally new departure. From that early period when the men of the stone age rudely outlined the mammoth and the reindeer on stone or ivory, the only means of representing men and animals, natural scenery, or the great events of human history, had been through the art of the painter or the sculptor. It is true that the highest Greek, or mediæval, or modern art, cannot be equaled by the productions of the photographic camera; but great artists are few and far between, and the ordinary or even the talented draughtsman can give us only suggestions of what he sees, so modified by his peculiar mannerism as often to result in a mere caricature of the truth. Should some historian in Japan study the characteristics of English ladies at two not remote epochs, as represented, say, by Frith and by Du Maurier, he would be driven to the conclusion that there had been a complete change of type, due to the introduction of some foreign race, in the interval between the works of these two artists. From such errors as this we shall be saved by photography; and our descendants in the middle of the coming

century will be able to see how much, and what kind, of change really does occur from age to age.

The importance of this is well seen by comparing any of the early works on ethnology, illustrated by portraits intended to represent the different "types of mankind," with recent volumes which give us copies of actual photographs of the same types; when we shall see how untrue to nature are the former, due probably to the artist having delineated those extreme forms, either of ugliness or of beauty, that most attracted his attention, and to his having exaggerated even these. Thus only can we account for the pictures in some old voyages showing an English sailor and a Patagonian as a dwarf beside a giant; and for the statement by the historian of Magellan's voyage, that their tallest sailor only came up to the waist of the first man they met. It is now known that the average height of Patagonian men is about five feet ten inches or five feet eleven inches, and none have been found to exceed six feet four inches. Photography would have saved us from such an error as this.

There will always be work for good artists, especially in the domain of color and of historical design; but the humblest photographer is now able to preserve for us, and for future generations, minutely accurate records of scenes in distant lands, of the ruins of ancient temples which are sometimes the only record of vanished races, and of animals or plants that are rapidly disappearing through the agency of man. And, what is still more important, they can preserve for us the forms and faces of the many lower races which are slowly but surely dying out before the rude incursions of our imperfect civilization.

Among the numerous scientific discoveries of our century we must give a very high, perhaps even the highest, place to spectrum analysis. Not only because it has completely solved the problem of the true nature and cause of the various spectra produced by different kinds of light, but because it has given us a perfectly new engine of research, by which we are enabled to penetrate into the remotest depths of space, and learn something of the constitution and the motions of the constituent bodies of the stellar universe. Through its means we

have acquired what are really the equivalents of new senses, which give us knowledge that before seemed absolutely and forever unattainable by man.

The solar spectrum is that colored band produced by allowing a sunbeam to pass through a prism, and a portion of it is given by the dewdrop or the crystal when the sun shines upon them; while the complete band is produced by the numerous raindrops, the colored rays from which form the rainbow. Newton examined the colors of the spectrum very carefully, and explained them on the theory that light of different colors has different refrangibilities—or, as we now say, different wave lengths. He also showed that a similar set of colors can be produced by the interference of rays when reflected from the two surfaces of very thin plates, as in the case of what are termed Newton's rings and in the iridescent colors of thin films of oil on water, of soap bubbles, and many other substances.

These color phenomena, although very interesting in themselves, and giving us more correct ideas of the nature of color in the objects around us, did not lead to anything further. But in 1802, the celebrated chemist, Dr. Wollaston, made the remarkable discovery that the solar spectrum, when closely examined, is crossed by very numerous black lines of various thicknesses, and at irregular distances from each other. Later, in 1817, these lines were carefully measured and mapped by Fraunhofer; but their meaning remained an unsolved problem till about the year 1860, when the German physicist, Kirchhoff, discovered the secret, and opened up to chemists and astronomers a new engine of research whose powers are probably not yet exhausted.

It was already known that the various chemical elements, when heated to incandescence, produce spectra consisting of a group of colored bands, and it had been noticed that some of these bands, as the yellow band of sodium, corresponded in position with certain black lines in the solar spectrum. Kirchhoff's discovery consisted in showing that, when the light from an incandescent body passes through the same substance in a state of vapor, much of it is absorbed, and the colored bands

become replaced by black lines. The black lines in the solar spectrum are due, on this theory, to the light from the incandescent body of the sun being partially absorbed in passing through the vapors which surround it. This theory led to a careful examination of the spectra of all the known elements, and on comparing them with the solar spectrum it was found that in many cases the colored bands of the elements corresponded exactly in position with certain groups of black lines in the solar spectrum. Thus hydrogen, sodium, iron, magnesium, copper, zinc, calcium, and many other elements have been proved to exist in the sun. Some outstanding solar lines, which did not correspond to any known terrestrial element, were supposed to indicate an element peculiar to the sun, which was therefore named helium. Quite recently this element has been discovered in a rare mineral, and its colored spectrum is found to correspond exactly to the dark lines in the solar spectrum on which it was founded, thus adding a final proof of the correctness of the theory, and affording a striking example of its value as an instrument of research.

The immediate effect of the application of the spectroscope to the stars was very striking. The supposition that they were suns became a certainty, since they gave spectra similar in character and often very closely resembling in detail that of our sun.

LIGHT AND ITS USES

Color

By ELISHA GRAY

IN the musical scale each note differs from the other in the matter of pitch; and pitch, as we have seen, is the rate of vibration per second. Colors differ in pitch the same as musical tones, and there are about an octave of them. If we allow a beam of sunlight to come into a dark room through a small aperture and let it fall on a white screen, there will appear a round spot of white light that is an image of the sun. If now we intercept the beam of light with a prism placed with the edge downward, there will appear on the screen a band of colors, one above the other. They will appear in the following order, beginning at the bottom: Red, orange, yellow, green, blue, indigo, violet, and the whole is called the solar spectrum. When a ray of light passes from a rarer to a denser medium—as from air through glass—the rays are bent out of their course, and the bend is different for each color. This bend is called refraction. The red ray is the least refracted and the violet the most; and this is why the violet appears at the top of the band of colors. This difference of bend in the color rays is due to the difference of wave length. For light, like sound, has a definite wave length for each vibration period. In order that we may better understand, let us go back a little and tabulate the vibration period of each color:

Red	477,000,000,000,000 per second
Orange	506,000,000,000,000 per second
Yellow	535,000,000,000,000 per second

Green.....	577,000,000,000,000 per second
Blue.....	622,000,000,000,000 per second
Indigo.....	658,000,000,000,000 per second
Violet.....	699,000,000,000,000 per second

It will be seen from the foregoing table that the vibration rate per second increases from red to violet. The wave length of the slowest vibration, to wit, red, is the greatest, the same as in sound, and the shortest is that of the most rapid—violet. The more waves there are in a given distance the greater the bend will be in passing from one medium to another.

The red ray has 39,000 waves to an inch, hence the wave length of red is one thirty-nine-thousandth of an inch. The violet ray has 57,000 waves to the inch. The red ray, having the fewest number of waves to the inch, is therefore bent out of its course the least, while the violet ray, having the greatest number per inch, is bent the most out of its course in passing through the prism. It will be seen from the foregoing why the colors are dispersed in passing through the prism.

It will be remembered that the wave length of a sound tone with 256 vibration periods per second was four feet and four inches in air. It will be noted that there is a vast difference between the wave length of a sound tone and that of a color tone.

You ask, why do different objects seem to have different colors? Color as a sensation is the effect of ether waves impinging upon the retina of the eye. When these waves enter the eye at the rate of 477,000,000,000,000 per second there is a sensation produced in the brain that we call red, but when the retina is agitated by 699,000,000,000,000 ether waves per second we experience the sensation of violet, and the same is true of the other colors; so that for each variation of rate within the limits of color there will be a corresponding variation of color sensation. Having now established the rates of motion and the wave lengths of the different colors of light, we are prepared to explain the phenomena of color as they appear on various objects that come within the range of our vision.

It has been stated in a preceding chapter that we see all non-luminous objects by reflected light. If a ray of white light

falls upon a black surface, all the colors are absorbed and none reflected. Darkness is the absence of light, hence we have black, which is simply the absence of all color. If a ray of light falls upon an object that absorbs all the colors but red, then red alone will be reflected to the eye and we have the sensation which belongs to that color, because the rate of vibration that produces this sensation of red is the only one that is reflected. This same thing would be true of all the colors. If an object has a violet color it is because all the other colors are absorbed and violet only is reflected to the eye, hence the sensation of violet.

When a color is absorbed it becomes heat. If we wear dark clothing the sun will seem much hotter than when we are clothed in white. The former absorbs the color vibrations, which become heat, while the latter reflects them. If we have some color tint which arises from a mixture of colors, it is because the object so tinted is able to reflect two or more color vibrations, the resultant of which is the tint. Colors, like sounds, may be mixed in an infinite number of proportions, and each change of proportion is not only a change of the physical conditions of the ether between the reflecting substance and the eye, but a change of sensation, or emotion. The blending of color motion affects our emotional nature somewhat as the blending of sonorous tones does. They may be harmonious and pleasing, or they may be inharmonious and irritating. Women are as a rule more sensitive to color tints than men, because their training has been such as to make them so. We hear them say, "Those colors fight," which is another way of saying that they are inharmonious and grate upon their sensitive nerves.

Color art is not yet developed so that it is a language of the emotions in the same sense that music is. Not long ago it could have been said that music was not an art. It may be that at some future time the art of color, so crudely developed now, will be brought to the same state of perfection as a language for the expression of emotion that the art of music has reached at the present time.

It will be impossible to give you more than a very few fun-

damental facts relating to this beautiful science, because so many of the phenomena, to be understood intelligently, need the aid of experiment and illustration that cannot be had here. The fundamental thought running through all the phenomena of sound, heat, and light, as well as electricity, is motion; motion, as related to our sense perceptions, and motion as related to all the innumerable phenomena of nature.

Let us now continue our investigation of color, from the standpoint of definite rates of motion and definite lengths of impulse. Every schoolboy is familiar with soap bubbles, and has spent many a happy hour blowing them. But he did not realize how many scientific truths could be extracted from them. The study of soap bubbles has led to some of the greatest discoveries.

The great Sir Isaac Newton made some of his most important discoveries by studying soap bubbles. Day after day he sat in his back yard blowing them and watching them rise in the air, displaying those varied hues of color that any one may see by trying the experiment. His neighbors became alarmed and took council among themselves as to what should be done for the "poor man." Poor, indeed, he was to those ignorant souls. But how rich was his life to the millions who have followed him!

For getting the finest results in the formation of soap bubbles, the best medium is a solution of castile soap and glycerine in the proportion of one part glycerine to two of the saturated solution of soap. First, take a common glass tumbler and dip the mouth of it into the solution, and by careful handling we can get a film of soap and glycerine stretched across the mouth of the tumbler. Now turn the tumbler over on its side and immediately bands of color will appear running across the film. You will notice that these colors change. We have already seen that every color has a definite wave length and a definite rate of vibration per second. A color will be reflected from the film when its thickness is one-fourth of the wave length that belongs to that color. We saw that when sound was reflected or reënforced by a hollow tube closed at one end, the tube was one-fourth the length of the sound wave. The same law holds good with color motion. The reflection is from the

back of the film, as sound is from the bottom of the tube. If the film is thick enough, the first color that will appear is red, and after that the others in the order of their succession in the solar spectrum. The film is constantly growing thinner at the top, by the stretching produced by gravity, and when it reaches the thickness of one one-hundred-and-fifty-six-thousandth of an inch the red ray will appear, as that is one-fourth the wave length of the red ray. When all the phases of color have appeared and passed down, there appears a patch of gray at the top of the film which tells us that it is stretched to its limit. And now it breaks. Knowing as we do the wave lengths of color, we are able to measure the thickness of the film. If violet has appeared on the film we know that it is not over one-fourth the thickness of a wave length of that color, which would be one two-hundred-and-twenty-eight-thousandth of an inch. This gives us also some idea of the size of a molecule of water, as the film cannot stretch to a thinness beyond the diameter of the molecule; although the film may break by its own weight long before its thickness has been reduced to that diameter.

Light waves may be made to interfere with each other the same as sound waves. If two sets of light waves of the same wave length are so related to each other that one set of waves falls in the depression between the other set, the result is darkness.

We have seen that if all the colors of a sunbeam are totally reflected to the eye from an object, the color of the object is white. But if some one of the colors is only partially reflected or entirely absorbed, the composite effect would be something away from white. There is an inconceivable number of variations and proportions of color, and as each variation may produce a variation of tone, or tint, we can see how all the delicate shadings of a poem or a symphony in color may be produced. Some time color and color tones may be classified and arranged in their order of succession and combination, and by some sort of instrument that will cause them to appear and disappear—played upon as we do upon a musical instrument to produce the effect of sound coloring. Color will then become a language of emotion, as music is now.

LIGHT AND ITS USES

The X-Rays

By JOHN TROWBRIDGE*

SINCE the publication of Hertz's paper on the penetration of thin sheets of metal, notably aluminum, by the cathode rays, interest in the remarkable phenomena investigated first by Professor Crookes has been reawakened to a marked degree; and most physicists during the past five years have regarded the subject of cathode rays as the most important one in electricity. In 1893 Lenard succeeded, by means of a Crookes tube provided with a small aluminum window, in detecting the cathode rays outside the tube in the air space of an ordinary room. He used paper disks covered with a very fluorescent substance, which became luminous when the cathode rays struck them; and he also succeeded in showing photographic effects of the rays. Now Röntgen, by the use of ordinary dry plates and without the use of an aluminum window, has taken photographs through wood and through the human hand by means of what he terms the x -rays, which he supposes are excited either in the glass walls of the Crookes tube or in the media outside the tube by means of the cathode rays.

We see, therefore, that the literature of the subject must be sought in the papers of Crookes, Hertz, Lenard, and Röntgen; and the interest in the mysterious manifestations of these invisible rays is twofold; first, in regard to the possible application of the phenomena to surgery, since the rays show a specific absorption, passing more easily through the flesh than through

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bones or glass or metallic particles; and, secondly, in relation to the questions whether we are dealing here with radiant matter shot forth from the negative pole or cathode or with longitudinal waves of electricity.

Let us examine the possibility of the practical application of the cathode photography to surgery. The term cathode is applied to the zinc pole or negative pole of an ordinary battery. It is that terminal of an electrical machine which glows least in the dark when the machine is excited. It is the shortest carbon in the ordinary street electric lamp. The positive carbon or anode burns away twice as fast as the negative carbon or cathode. If the electric light is formed in a high vacuum by means of a great electro-motive force, we no longer have a voltaic arc or a spark; instead of this the exhausted vessel is filled with a feeble luminosity, and a beam of bluish rays is seen to stream from the negative terminal or cathode. When these rays strike the glass walls of the vessel they excite a strong fluorescence. If the glass contains an oxide of uranium, this fluorescence is yellow; if it contains an oxide of copper, it is green. Röntgen supposes that this fluorescence excited by the cathode rays is connected in some way with the formation of what he terms the x -rays. Now, a photograph of the bones in the hand, for instance, can be obtained by placing a sensitive plate in an ordinary photographic plate-holder. Resting the hand on the undrawn slide in the daylight, with the palm of the hand outward and toward the cathode, and about six inches away from it, the bones of the hand are thus brought in the nearest possible position to the sensitive plate. At the time of the present writing, the breast and the abdomen of the human body present too great thickness for successful photographs, and the attempts to obtain representations of the cavity in which the brain is situated have been failures, since the rays do not show any marked difference in fleshy tissues. Nothing can be obtained in these attempts to photograph the brain but a contour of the cavity in which it is situated, and possibly a shadowy representation of a bullet which might be imbedded in the head. The method of obtaining a successful photograph of the hand shows the present limitations of the method. In

order to obtain a fairly sharp shadow of a bone or of a shot, it should not be more than an inch away from the sensitive plate. The term shadow, however, is somewhat misleading. The photograph of the hand by the x -rays is entirely different from one produced by resting the hand in a similar position to that above described against an uncovered sensitive plate in a dark room and then lighting a match. By the last method we should obtain a true shadow of the hand, the flesh would throw as dense a shadow as the bones, and the latter could not be detected in the general blackness. In the cathode photograph, on the other hand, a difference in absorptive power is shown: the flesh looks like a hazy film around the skeleton, and even the medulla cavities can be made out, and the varying thickness of the bones is more or less shown. This specific absorption is of great scientific interest as well as of practical importance.

Now, these x -rays will penetrate several inches of wood, with varying amount of absorption, but they are almost entirely cut off by glass as thick as a window pane. They pass through thin layers of aluminum, even layers as thick as a silver ten-cent piece, while the silver coin almost entirely intercepts them.

It therefore immediately occurs to one, Why not return to Lenard's tube, provide a Crookes tube with an aluminum window, and thus save the great absorption of the glass walls of the tube? There are certain practical difficulties in the way. The aluminum must be very thin. Lenard used a window which was about one eight-thousandth of an inch thick, and it was necessarily very small, in order to stand the atmospheric pressure. An aluminum window one eighth of an inch thick, or as thick as a ten-cent piece, would absorb nearly as much as the glass walls of the present forms of Crookes tubes, which are not more than one sixtieth of an inch thick. Glass vessels seem at present to be more practical than any composite form, in which aluminum is glued to a glass-supporting vessel: first, because it can be blown very thin, and in a shape strong enough to withstand the atmospheric pressure; secondly, because the occluded air can be more effectively driven off the inner walls of the vessels by heating it while it is being ex-

hausted than it can be expelled from a vessel of any other material.

To obtain successful photographs, the exhaustion of the air must be pushed to a high degree; and this is also interesting from the scientific point of view. Moreover, a high electro-motive force is necessary. Pictures can be taken in less than one minute of the skeleton of the human hand by means of high vacua tubes excited by high electro-motive force. Even in this bare recital of the present limits of the application of the x -rays to photography, we perceive great possibilities in the application of the method to the surgery of the human extremities. There is no doubt that small foreign bodies, like shot and pieces of glass, can be detected in the fleshy tissues of the hand. Certain accessible regions of the body, like the mouth, can possibly be examined by placing a sensitive film inside the mouth and the cathode outside of the cheek; and it does not seem improbable that a suitable cathode vessel can be inserted into certain abdominal regions and a photograph be obtained by placing a sensitive plate on the outside of the body. By employing two cathodes, at the proper distance apart, stereoscopic representations of the bones can be obtained, and an estimate formed of the position of foreign bodies.

Let us now turn to some of the interesting scientific questions which have arisen in regard to this apparently new manifestation of the cathode rays. In the first place, they are apparently not refracted by paraffine, vulcanite, or wood, or by any substance which is penetrated by them. To test this, I employed a double-convex lens of wood and also a double-concave lens of the same material. I placed two copper rings in the concavity of the double-concave lens of wood, and also a similar copper ring outside the lens at the same height from the sensitive plate, as one of the rings which rested on the wood of the lens. I also placed a ring on the double-convex lens, and employed two cathodes to obtain two shadows from different positions. The thickness of the wooden lenses varied from half an inch to three quarters of an inch. The images obtained through the wood of the lenses were not distorted or changed in figure in any way by the wood, and therefore no

refraction could be observed by this method. On account of the quick diffusibility of the rays, no accurate method of determining a possible index of refraction seems possible. If the photographic effect is due to longitudinal waves in the ether, and if these waves travel with great velocity, no refraction would probably be observed. Maxwell's electro-magnetic theory of light supposes that only transverse waves are set up in the ether, and no longitudinal waves exist. On the other hand, Helmholtz's electro-magnetic theory of light postulates longitudinal waves as well as transverse waves. The longitudinal waves travel with an infinite velocity. Is it therefore possible that the x -waves are the longitudinal waves of Helmholtz's theory? Our apparent inability to refract the rays lends color to this hypothesis. Röntgen, in the preliminary account of his experiments, intimates that the phenomena may be due to longitudinal waves, and in a late article in the "*Annalen der Physik und Chemie*," by Jaumann, entitled "Longitudinal Light," Maxwell's electro-magnetic equations are modified so as to embrace the phenomenon of cathode rays; and the author shows that even Maxwell's theory can, under certain conditions, give a longitudinal wave.

The Röntgen phenomenon seems to be a manifestation of cathode rays brought to light and endowed with great practical interest by its application to dry-plate photography. When we return to the classical investigation of Lenard mentioned in the beginning of this article, we are impressed by an apparently crucial experiment which he describes in regard to the existence of an ether. He caused the cathode beam to pass out of his high vacua through an aluminum window into another tube about three feet long, which had been exhausted to such a high degree that no electrical discharge would pass through it. It seemed, therefore, to have an infinite electrical resistance. No cathode beam could be generated in it; nevertheless, by moving suitable disks of fluorescent matter from point to point in the tube by means of an outer magnet which attracted bits of iron on the disks, Lenard showed that the cathode beam passed through the vacuum. Energy passed into the vacuum and could be detected from point to point. We can conceive of

its passing through the ether in the tube by a wave motion, but not by a molecular movement, for there were no molecules to move. The molecular bombardment must have stopped at the aluminum window, and the resulting energy may have been propagated by ripples in the ether. This experiment of Lenard seems to me the most interesting one in the subject of cathode rays. The greatest mystery, however, which envelops the subject is the action of the x -rays on bodies charged with electricity. When the rays fall on, for instance, a charged pith ball, the charge disappears. A positive as well as a negative charge is dispelled by the x -rays. The energy of the medium about the pith ball is changed to a marked degree, and in this phenomenon we seem to be brought closer to a wave theory in a medium than to a molecular theory of movement of matter.

LIGHT AND ITS USES

X-Ray Photography

By RAY STANNARD BAKER

PERHAPS no inventor ever achieved world-wide distinction so quickly as Dr. William Konrad Röntgen. He discovered his famous x -rays on November 8, 1895; in December he described them before the Würzburg Physico-Medical Society; in January the marvel of the new rays which penetrate and photograph through almost every known substance was known all over the world, as well to newspaper readers as to the learned societies. A few months later many prominent scientists both in Europe and in America, were experimenting with Röntgen's rays, and within a year they had become a regular and exceedingly important factor in surgical operations. Moreover, no one disputed the originality of Dr. Röntgen's discovery; he had invented the first machine for photographing through solid substances, for taking pictures of the skeleton framework of the human body through the flesh. No one ever before had done that, and the scientific world was quick with its appreciation and liberal with its honors.

And yet this discovery, which many scientists rank side by side with Lister's system of antiseptics in its importance as a life saver, was not the result of happy chance. It was not mere luck. At the time that Dr. Röntgen saw the x -rays shimmering and glowing for the first time on a bit of sensitive paper he was past fifty years old, and during the greater part of his life he had been working quietly but industriously and thoughtfully with the great problems of physics and electricity. He laid the foundation of his career in a thorough education at

Zurich, his birthplace, and at Utrecht. Seven years before the discovery he had become a professor at the Royal University in the quaint old Bavarian town of Würzburg. Here, in a bare little laboratory in an equally modest two-story house, with few of the modern appliances, he made his famous experiments, and from here he went out, when the world heard of him, to receive the praise and decorations of his emperor. And after that he returned to his work, just as if he wasn't famous.

Dr. Röntgen (pronounced Rentgen) is a tall, slender, somewhat loosely built man, with a bushy beard and long hair rising straight up from a high white forehead. When he is excited or much in earnest he thrusts his fingers through this mass of hair until it bristles all over his head. He has an amiable face with kindly although penetrating eyes. His voice is full and deep, and he speaks with the rapidity of great enthusiasm. Indeed, his whole bearing tells of boundless energy and unremitting vigor. One visitor compared him on first sight to an amiable gust of wind.

Previous to the discovery which made him famous, Dr. Röntgen had actually been producing and working with x -rays for some time without knowing it. Indeed, other scientists had been doing much the same thing—experimenting all unconsciously on the very verge of the greatest discovery of years, but it remained for Dr. Röntgen, with his keener scientific insight, to see the unseen.

The famous electrician Hertz, whose discoveries have made possible more than one great invention, had tried sending a high-pressure electric current through a vacuum tube, a so-called Crookes tube. A vacuum tube is a vessel of very thin glass, having a platinum wire fixed in each end. This vessel is as nearly empty of everything as human ingenuity can make it; even the air is pumped out until only one one-millionth of an atmosphere remains. Hertz connected one of these tubes to the poles of his battery by means of the platinum wires. When the discharge began he observed that the anode—that is, the end of the tube connected with the positive pole of the battery—gave off certain peculiar and faint bands of light. But these were quite insignificant compared with the brilliant

and beautiful glow at the other or negative end of the tube, which is called the cathode. This glow resembled somewhat the fierce burning of an alcohol lamp, only it was softer, more evanescent, and more striking in its coloring. It produced brilliant phosphorescence in glass and many other substances, and Professor Lenard, Hertz's assistant, observed, in 1894, that the rays—"cathode rays," as they were called—would penetrate thin films of wood, aluminum, and other substances. But this was as far as any of the experimenters who preceded Röntgen succeeded in going.

Strangely enough, both Hertz and Lenard produced *x* rays in abundance without knowing it. These were, indeed, present in the glow from the cathode, only they were entirely invisible to the human eye. They are different from the rays described by Lenard, in that they are not deflected—that is, turned aside—by a magnet, and they are incomparably more powerful in range and in penetrating power. It will be seen, therefore, that while Dr. Röntgen was not working in a wholly new field, his discovery is none the less entirely original.

The discovery itself was made in a peculiarly interesting way. Dr. Röntgen had been experimenting steadily for several weeks with his Crookes tubes. One day he had covered the tube with a light-excluding black shield. Then he had darkened his laboratory so that not a ray of light could anywhere enter. To the eye everything was absolutely black. When the electric current was turned on, the hooded tube did not show even a glint of light; but something on a shelf below began to glow, very strangely. It was a piece of sensitive paper—barium platino-cyanide paper. Dr. Röntgen knew that no light could come from the tube, because the shield that covered it was wholly impervious to light—even the strongest electric light. Where, then, did it come from? Dr. Röntgen began at once an eager investigation, moving the sensitive paper from side to side and covering the tube with a still denser screen. And finally he came to the conclusion that certain unknown rays, whether of light or not, he did not know, were actually coming through the screen, and giving the sensitive paper a distinct luminescence. It was contrary to all reason, to everything

that the text-books taught, and yet Dr. Röntgen was forced to believe it. And having discovered the existence of the new rays, he began at once to experiment with them. He found that they readily penetrated paper, wood, and cloth, and that the thickness of these mediums made little difference. That is, they would penetrate a thick book almost as easily as they would a single sheet of paper. Then he tried photographing, and found to his astonishment that the rays affected the sensitive film of the photographic plate, leaving the shadows of the objects exposed plainly outlined. For instance, he placed bits of platinum, aluminum, and brass inside of a wooden box, and found that not only did he get skiagraphs (shadowgraphs) of them through the wood, but all the nails that held the box together and the brass hinges were likewise reproduced. Then he photographed a spool of wire, the wooden ends of the spool leaving a very faint shadow, and the wire a dark one. When he tried glass, which is one of the most transparent of substances so far as ordinary light is concerned, he found that the new rays passed through it only with difficulty, and that aluminum was much more transparent to them than glass. In other words, if we lived in an x -ray world we might use aluminum for windows to let in the x -ray "light," and glass for shutters to keep it out.

After many experiments of this kind, it suddenly occurred to Dr. Röntgen that if the new rays penetrated all manner of substances, they would also penetrate the human body; that, in fact, they were probably going straight through his hands and his head as he worked with them. So he placed his hand, palm down, on a photographic plate, still in its black holder, arranged the Crookes tube above it, turned on the current, and in a short time he had a photograph, dim, it is true, but perfect, of the bony framework of his hand—the first of the kind ever taken, and a marvel up to that time absolutely inconceivable.

A little later he built a closet of tin just big enough to accommodate one man comfortably, and fitted it up with an aluminum window. Outside of the window he placed his new apparatus. Only the new rays would, of course, shine through

the aluminum, and he could study them at his leisure. But after long and careful experimenting he could not decide what the new rays really were, and although many theories have been advanced by prominent scientists, a really satisfactory explanation is still wanting. It is pretty generally believed, however, that Röntgen's rays are only a "mode of motion" through the ether—that is, they are produced by a certain peculiar kind of vibration in the ether. Dr. Röntgen himself gave them the name "*x*-rays"—the unknown rays.

But if the exact nature of the rays was a mystery, their uses and importance became familiar almost immediately. The apparatus was so simple that it could be fitted up in almost any laboratory. It consisted merely of a battery or dynamo current; a coil, usually a Rhumkorff coil, for intensifying the current, and a Crookes tube, which might have any one of twenty odd shapes. As a result of this simplicity thousands of surgeons and scientists were able to prepare experimental apparatus, and some of the results in this country were excellent, especially in photographing the human skeleton.

Even Edison, the greatest of American inventors, took up the work with great enthusiasm, and he shortly invented a curious but simple device by means of which one may actually see the bones of the hand or foot through the flesh. He called it the fluoroscope. It is merely a wooden box, larger at one end than at the other, the smaller end being so constructed and padded with cloth that it will fit exactly over the eyes without admitting any light. The other end of the box is covered with a sheet of thin cardboard coated with a chemical compound which becomes fluorescent—that is, shines or glows—when placed in range of the *x*-rays. By holding this box between one's eyes and a Crookes tube, and placing one hand on the sensitive cardboard, the *x*-rays will readily pierce the flesh, and the dark shadow of the skeleton of the hand may be seen. In this way a doctor can tell quickly the location of a bullet or a needle in the hand or foot, for he is able to look through the flesh as if it were glass.

The Röntgen rays have been put to many marvelous uses, most of them connected with bone photography in surgery



THOMAS A. EDISON IN HIS LABORATORY

cases. And, strangely enough, when a physician is ready to photograph a broken arm, for instance, to see if it is properly set, he never thinks of removing the splints or the bandages; he simply photographs through them. And that is the reason why such a photograph often shows pins and buckles. Frequently, in cases where the patient is very weak, the photograph is taken through the bed-clothes as well as through the bandages—it doesn't make the slightest difference to these wonderful rays. It takes from two minutes to more than an hour to get a good skiagraph, but the operation is no more painful, if we count out the necessity of keeping still, than having a snap-shot taken.

One of the earliest skiagraphs, showing the medical importance of the x -rays, was taken in England. A boy of nineteen had injured his little finger playing ball, so that it was bent at the last joint, and he could neither extend it nor bend it farther down. Any attempt to do so caused him sharp pain. Before the skiagraph was taken the doctors declared that the finger must be amputated. A skiagraph showed, however, that there was only a little bridge of bone uniting the last two joints, thereby preventing the proper flexing of the finger. As soon as this was known an anæsthetic was administered, and by the use of a little force this bridge of bone was snapped, and the finger saved. That was the first finger to the credit of Dr. Röntgen's discovery.

Since then the x -rays have been used constantly for finding bullets embedded in the flesh— x -ray machines are now taken to war with every civilized army—for finding needles that have been driven into the foot, for examining deformities of the bones, and, more recently, for photographing foreign bodies in the larynx and windpipe, and even in the stomach. Think of the sufferings caused by probing for bullets, shot, and needles in the flesh, all saved by an easily taken skiagraph!

An English woman came to a doctor saying that she was suffering tortures from her shoes, so that she found it difficult to walk, and she even wanted some of her toes amputated. A skiagraph showed exactly what the trouble was. She had been wearing shoes much too small for her, and the bones had be-

come woefully twisted and bent. One sight of the photograph convinced her that she must wear broad-soled shoes. In a somewhat similar case in Austria, the doctors found that the great toe of the patient was twice as large as it should be. They found by feeling that there were two bones instead of one, but they could not tell which was the normal bone and which the one to be removed. A skiagraph showed the whole condition instantly.

One of the strangest uses to which *x*-rays ever have been put was at the instance of a Philadelphia woman. She had been traveling in Egypt, and had brought home what she believed to be the hand of a mummy. But some of her friends told her how Egyptian curiosities are likely to be manufactured and sold to unsuspecting travelers as genuine relics. One friend, himself a great traveler, assured her that she had bought a mere mass of pitch, plaster of Paris, and refuse mummy-cloth, not a hand. For a long time there was no way of deciding the question, until at last the owner of the relic had an *x*-ray photograph taken. And lo and behold! there in the picture was the complete skeleton of the hand of some ancient Egyptian; the relic was genuine, after all.

Another curious and important use of *x*-rays is in determining genuine from imitation diamonds. A European scientist has made many tests in this field, and he finds that while the *x*-rays will penetrate the genuine diamond and leave almost no shadow in the photograph, the false ones are nearly opaque to the rays, and appear very dark in the photograph. This unusual new test may some time supersede all others.

A great many experiments have been made looking to the use of *x*-rays in curing diseases. Several prominent physicians assert that the new rays kill all germs—consumption, typhoid fever, diphtheria, and so on—and that by applying them properly to the diseased portion of the body a cure may be effected.

LIGHT AND ITS USES

The Eye as an Optical Instrument

By AUSTIN FLINT*

I HAVE often wondered whether the statement, occasionally made by physicists, that the human eye is not a perfect optical instrument, is an expression of human vanity or of an imperfect knowledge of the anatomy of the eye and the physiology of vision; and I have come to the conclusion that the latter is the more reasonable theory. The approach to perfection in modern telescopes and microscopes is wonderful indeed; but as physiologists have advanced the knowledge of vision, the so-called imperfections of the eye have been steadily disappearing; and even now there is much to learn. Viewed merely as an optical instrument, an apparatus contained in a globe less than an inch in diameter, in which is produced an image practically perfect in form and color, which can be accurately adjusted almost instantly for every distance from five inches to infinity, is movable in every direction, has an area for the detection of the most minute details and at the same time a sufficient appreciation of large objects, is double, but the images in either eye exactly coinciding, enables us to see all shades of color, estimate distance, solidity, and to some extent the consistence of objects, the normal human eye may well be called perfect. The more, indeed, the eye is studied in detail, the more thoroughly does one appreciate its perfection as an optical apparatus.

Were it not for a slight projection of the cornea (the trans-

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parent covering in front) the eye would have nearly the form of a perfect globe a small fraction less than an inch in diameter. It lies in a soft bed of fat, is held in place by little muscles and a ligament which is so lubricated that its movements take place with the minimum of friction. It is protected by an overhanging bony arch and the eyelids, the eyelashes keeping away dust, and the eyebrows directing away the sweat. Situated thus in the orbit, the eyes may be moved to the extent of about forty-five degrees; but beyond this it is necessary to move the head.

The accuracy of vision depends primarily upon the formation of a perfect image upon the retina, which is a membrane, sensitive to light, connected with the optic nerve. That such an image is actually formed has been demonstrated by an instrument, the ophthalmoscope, which enables us to look into the eye and see the image itself. Although the image is inverted, the brain takes no cognizance of this, and every object is appreciated in its actual position. The image is formed in the eye in the way in which an image is produced and thrown on a screen by a magic lantern.

When a ray of light passes obliquely from the air through glass, water, or other transparent media, it is bent, or refracted, and the angle at which it is bent is called the index of refraction. In passing to the retina, the rays of light pass through the cornea, a watery liquid (the aqueous humor) surrounding the lens, the crystalline lens, and a gelatinous liquid (the vitreous humor) filling the posterior two-thirds of the globe, all of which have the same index of refraction. This provides that a ray of light, having once passed through the cornea, is not refracted in passing through the other transparent media, except by the curvatures of the crystalline, which is a double-convex lens situated just behind the pupil. The rays of light are not reflected within the eye itself, for the opaque parts of the globe are lined with a black membrane (the choroid), as the tube of a microscope is blackened for a similar purpose. Practically, the bending of the rays of light is produced by the curved surface of the cornea and the two curved surfaces of the double-convex crystalline lens. These three curved surfaces bring the rays from an object to a focus exactly at the retina in a normal

eye. When, however, the eye is too long, the focus is in front of the retina unless, in near vision, the object be brought very near the eye, and the person is near-sighted. For ordinary vision, such persons must wear properly adjusted concave glasses to carry the focus farther back. When the eye is too short, the focus is behind the retina, and the person is far-sighted and must wear convex glasses. The first condition is called myopia, and the second, hypermetropia; but in most persons who are obliged to wear convex glasses in advanced life, the crystalline lens has become flattened and inelastic, the diameter of the eye being unaltered. This condition is called presbyopia, which means a defect in vision due to old age.

One of the wonderful things about the eye is the mechanism by which a perfect image is formed. What is called the area of distinct vision is a depression in the yellow spot of the retina, which is probably not more than a thirty-sixth of an inch in diameter. It is with this little spot that we examine minute details of objects. If we receive the rays of light from an object upon a double-convex lens and throw them upon a screen in a darkened room, the image of the object appears upon the screen; but in order to render this image even moderately distinct it is necessary to carefully adjust the lens, or the combination of lenses, to a certain distance, which is different for lenses of different curvatures. In the human eye the adjustment is most accurately made, almost instantaneously, for any desired distance, not by changing the distance between the crystalline lens and the retina, but by changing the curvature of the crystalline lens itself. The way in which this is done has been known only within the last few years. The lens is elastic, and in a quiescent or what is called an indolent condition, is compressed between the two layers of the ligament which holds it in place. In this condition, when the rays from distant objects are practically parallel as they strike the eye, the lens is adjusted for infinite distance. When, however, we examine a near object, by the action of a little muscle within the eyeball the ligament is relaxed and the elastic lens becomes more convex. This action is called accommodation, and is voluntary, though usually automatic. The fact that it is voluntary

is illustrated by the very simple experiment of looking at a distant object through a gauze placed a few feet from the eye. When we see the distant object distinctly, we do not see the gauze; but by an effort we can distinctly see the meshes of the gauze, and then the object becomes indistinct. In some old persons the lens not only becomes flattened, but it loses a great part of its elasticity and the power of accommodation is nearly lost.

The changes in the curvatures of the lens in accommodation have been actually measured. The lens itself is only about a third of an inch in diameter and its central portion is only a fourth of an inch thick. Adjusted for infinite distance, the front curvature has a radius of about four-tenths of an inch, while for near objects the radius is only about three-tenths of an inch. A curious experiment is looking at a minute object through a pinhole in a bit of paper or cardboard, when the object appears highly magnified. This is because the nearer the object is to the eye, the larger it appears. The shortest normal distance of distinct vision is about five inches; but in looking through a pinhole we can see at a distance of less than an inch, using a very small part of the central portion of the crystalline lens. Accommodation for very near objects is assisted, also, by contraction of a little band of fibers in the iris, about a fiftieth of an inch in width, immediately surrounding the pupil.

The most wonderful thing about the formation of a perfect image upon the retina is the mechanism of correction for form and color. In grinding lenses for the microscope, for example, it is mechanically easy to make a very small convex lens with perfectly regular curvatures—that is, each curvature being a portion of a perfect sphere; but in such a lens the focus of the central portion is longer than that of the parts near the edge; and when an object is in focus for the center it is out of focus for the periphery. This is a fatal objection to the use of uncorrected lenses of high power; but in microscopes it is corrected by combinations of lenses, reducing the magnifying power, however, about one-half. This is not all. When white light passes through a simple lens it is decomposed into the

colors of the spectrum. This is called dispersion, and it surrounds the object with a fringe of colors. The dispersion by concave lenses is exactly the opposite of the dispersion by convex lenses, so that this may be corrected by a combination of the two; but when this is done with lenses made of precisely the same material, the magnifying power is lost. Newton supposed that it was an impossibility to construct a lens corrected for color which would magnify objects; but since the discovery (in 1753 and 1757) of different kinds of glass having the same refractive power but widely different dispersive powers, perfect lenses have been possible.

In the human eye, a practically perfect image, with no alteration in color, is produced by a mechanism which human ingenuity cannot imitate. There is a slight error in the cornea, which is corrected by an opposite error in the crystalline lens; the iris plays the part of the diaphragm of optical instruments and shuts off the light from the borders of the crystalline lens, where the error is greatest, particularly in near vision; the curvatures of the lens are not perfectly spherical, but are such that the form of objects is not distorted; and while such curvatures are theoretically calculable, their construction is practically impossible, as experience has shown; different layers of the crystalline lens have different dispersive powers; and thus a practically perfect image, with no appreciable decomposition of white light, is formed on the retina.

Another wonderful thing about the eye, which adapts it most beautifully to our requirements, is the division of the sensitive parts of the retina into a very small area for distinct vision, which we use for reading, for example, and a large surrounding area in which vision is indistinct. If we saw with equal distinctness with all parts of the retina, the vision of minute objects would be confused and imperfect. As it is, the area of distinct vision is very small, probably less than one thirty-sixth of an inch in diameter. In this area, the distance between the separate sensitive elements is not more than one thirty-five-hundredth of an inch; while, if we pass from this only eight degrees, the distance is increased a hundred times. Still, in looking at any one object in the center of distinct

vision, the imperfect forms of surrounding objects are appreciated, warning us, perhaps, of the approach of danger.

The mechanism of distinct and indistinct vision has been understood only since 1876. The sensitive parts of the retina are little rods and cones forming a layer by themselves. In 1876, Boll discovered that in frogs kept in the dark the rods of the retina were colored a dark purple; but on exposure to light the color faded, becoming first yellow and then white. Since that time, physiologists have been carefully investigating visual purple and visual yellow. Just outside the layer of rods and cones are the dark cells which render the greatest part of the interior of the eye almost black. In the dark, these cells send little filaments between the rods and discharge a liquid which colors the rods alone. When the rods are thus colored, the eye is extremely sensitive, so that a bright light is dazzling and painful and obscures distinct vision. This is the reason why we cannot see distinctly when we come suddenly from the dark into a full light. In a few seconds, however, the color is bleached to a yellow and the difficulty passes away. When, on the other hand, we pass from a bright light into the dark, the retina has lost its sensibility from disappearance of the visual purple, and we cannot see at all until the purple is reproduced, as it is in the absence of light. This difference is not due to dilatation of the pupil in the dark and contraction under the influence of light, as is popularly supposed, for a person does not see better in the dark when the pupil has been fully dilated by belladonna.

In the little area of distinct vision there is never any visual purple. This area we always use with sufficient light for minute details of objects, making then the greatest use of the mechanism of accommodation. The area outside of this is used for indistinct vision, and as the color is then yellow instead of purple, it is only moderately sensitive. To express the conditions in a few words, the minute area for distinct vision is used by day, and the area for indistinct vision, with its visual purple, is used by night.

A very curious condition is what is known as night-blindness. Sometimes, in long tropical voyages, sailors become

affected with total blindness at night, while vision in the daytime is perfect. The glare of the sun in the long days bleaches the visual purple so completely that it cannot be restored in a single night, and the area of indistinct vision becomes insensible. This trouble is purely local and is remedied by rest of the eye. If one eye be protected by a bandage during the day, this eye will be restored sufficiently for the next night's watch, while the unprotected eye is as bad as ever. Snow-blindness in the arctic regions is due to the same cause.

We receive the impression of a single object, although there are two images—one in either eye; but it is necessary that the images be made upon corresponding points in the two retinae. If the angle of vision in one eye be deviated even to a slight degree by pressing on one globe with the finger, we see two images. One can appreciate how exactly these points must correspond when it is remembered that two rays of light appear as one only when the distance between them is one thirty-five-hundredth of an inch.

In either eye there is a blind spot, and this is at the point of penetration of the optic nerve; but, inasmuch as this spot is in the area of indistinct vision, and is so situated—a little within the line of distinct vision—that an impression is never made on both blind spots by the same object, this blindness is never appreciable, and the spot can be detected only by the most careful investigation.

Not the least of the wonders of the eye are connected with the appreciation of images made upon the retina by certain parts of the brain. It is literally true that a person may see and yet not perceive. It has happened, in certain injuries of the brain, that a person sees and reads the words in a book and yet does not perceive their significance. This is called word-blindness. In a certain portion of the brain is a part which enables us to recognize the fact that we see an object; yet this object conveys no idea. There are two of these so-called centers of vision, one on either side, and their action is partly crossed. When the center is destroyed on one side, the inner half of one eye and the outer half of the other eye are blinded. Farther back in the brain, however, is a center which

enables us to perceive or understand what is seen. When this center is destroyed we see objects and may avoid obstacles in walking, but persons, words, etc., are not recognized. This center exists only on the left side of the brain.

An impression, however short, made upon the retina is perceived. The letters on a printed page are distinctly seen when illuminated by an electric spark, the duration of which is only forty billionths of a second; but the impression remains much longer. Anything in motion appears to us in a way quite different from the single impression that we should have from an electric spark. In a picture representing an animal in motion, as it appears in an instantaneous photograph, the positions seem absurd and like nothing we have ever seen. In looking at a horse in action, the impressions made by the different positions of the animal run into each other, and art should represent as nearly as possible the sum or average of these impressions. It is also true that impressions are diffused in the retina beyond the points upon which they are directly received. This is called irradiation; and the impression is diffused farther for white or light-colored than for black or dark objects. It is well known that a white square looks considerably larger than a dark square of exactly the same size; or the hands in white gloves look larger than in black gloves.

I have described, in as simple a way as possible, some wonderful things about the eye ascertained and explained by modern investigations; but there are many interesting facts ascertained which space has not permitted me to discuss, and there still remains much that is not yet understood. The whole question of the appreciation of colors and of color blindness is still wrapped in mystery. We know that some persons cannot distinguish between certain colors, but the reason of this is obscure. Perfect sight can exist only when the eye is perfect. The form and color of objects may be distorted so that an inaccurate image is formed upon the retina, and this image, however imperfect it may be, is what is perceived by the brain. In hearing, the case is different. The waves of sound, if they be conducted to the internal ear, and if the nerve of hearing, with its terminations, be normal, cannot be modified in course

of transmission. Sounds are always appreciated at their exact value, except as regards intensity. Enough has been said about the eye, I think, to show that it is perfectly adapted to all requirements, and whatever defects it may seem to have, viewed as an optical instrument, render it more useful to us than if these apparent defects did not exist.

ASTRONOMY

Discoveries in the Heavens

By ALFRED RUSSEL WALLACE

MANY of the most striking discoveries in this science have been already described under Spectrum Analysis; but there remain a few great advances, due either to observation or to theory, which are of sufficient popular interest to demand notice in any sketch, however brief, of the scientific progress of the century.

With the single exception of Uranus, discovered by Herschel in 1781, no addition had been made to the five planets known to the ancients till the commencement of the present century, when Ceres, the first of the minor planets, was discovered in 1801, and three others between that date and 1807. No more were found till one was added in 1845, and another in 1847. Since that time no year has passed without the detection of one or more new planets belonging to the same system, till in September, 1896, their number amounted to 417. These small bodies form a kind of planetary ring situated between Mars and Jupiter, where it had long been suspected a planet ought to be found, because the distance between these older planets was so great as to be quite out of proportion with the regular increase of distance maintained by the other members of the system. It was at first thought that these asteroids or minor planets were the shattered remains of a much larger one; but more extended knowledge of the constitution of the solar system renders it more probable that they really constitute a ring of matter thrown off by the sun during its progressive contraction; and that some peculiar conditions have prevented its vari-

ous parts from aggregating into a single planet. This is rendered more probable by two other remarkable discoveries relating to meteors and comets, and to Saturn's rings, which will be discussed later on.

The next large planet added to our system is especially interesting, as affording a striking demonstration of the theory of gravitation, and a no less striking example of the powers of modern mathematics. It had been found that the motions of Uranus were not exactly what they ought to be, if due solely to the attraction of the sun and the disturbing influence of Jupiter and Saturn, and it was thought possible that there might be another planet beyond it to cause these irregularities. In the year 1843 a young Cambridge student (John Couch Adams) of the highest mathematical ability, determined to see whether it was not possible to prove the existence of such a planet; and having taken his degree as senior wrangler, he at once devoted himself to the work, and after two years of study and calculation he was able to declare that a planet which would account for the perturbation of Uranus must, if it existed, be at that time in a certain part of the heavens, and he sent his paper on the subject to the Astronomer-Royal in October, 1845. By an extraordinary coincidence, a French astronomer (Leverrier) had been for some years working out the motions of the various planets, and in doing so had also reached the conclusion that there must be another unknown body to produce the perturbations of Uranus, which were at that time unusually large. His calculations and results were published at Paris in November, 1845, and June, 1846, and he gave a position for the unknown planet differing only one degree from that given by Adams. On reading these papers, and seeing the agreement of two independent workers, the Astronomer-Royal asked Professor Challis, of the Cambridge Observatory, to search for the planet, and on doing so he actually observed it on August 4th, and again on August 12th; but having no accurate chart of that part of the heavens he could not be sure that it was not a small star. A month later it was found and identified at Berlin, from information furnished by Leverrier. It thus appears that Adams first privately announced the posi-

tion of the new planet, and that it was first observed at Cambridge; while the somewhat later announcement by Leverrier and discovery at Berlin were made public, and thus gained the honors of priority. The two discoveries were, however, practically simultaneous and independent, and the names of Adams and Leverrier should forever be jointly associated with the planet Neptune.

Other important discoveries in the planetary system are due to the increased power of modern telescopes and the greater number of observers. In 1877 two minute satellites of Mars were discovered at Washington, by means of the large telescope with a 25-inch object glass, then the largest in the world. These are remarkable in being exceedingly small, and very close to the planet. They are said to be only six or seven miles in diameter, and the inner one is only about 5,800 miles from the center, or 3,800 from the surface, of the planet, around which it revolves in less than eight hours; while the outer one is about 14,500 miles away, and revolves in a little more than thirty hours.*

Still more recently (in September, 1892), a fifth satellite of Jupiter was discovered by means of the great Lick telescope in California. This also is very small and very close to the planet, being less than half the diameter, or about 40,000 miles, from its surface.

Another very remarkable discovery is that of a system of symmetrical markings, covering a large part of the surface of Mars. They consist of a series of triangles or quadrilaterals bounded by straight lines, which are sometimes seen double, at other times single, or are even altogether invisible. Another peculiar feature is, that where these canals (as they are termed) intersect there is always a black circular spot, very distinct, and unlike any markings upon other parts of the surface. It is

* In "Gulliver's Travels," published in 1726, Swift describes the astronomers of Laputa as having "discovered two lesser stars, or satellities, which revolve around Mars; whereof the innermost is distant from the center of the primary planet exactly three of his diameters, and the outermost five; the former revolves in the space of ten hours, and the latter in twenty-one and a half." This is a wonderful anticipation, especially as to time of revolution, and if we substitute "radii" for "diameters," the distances are also very near.

a curious fact that the double canals sometimes enclose a space of more than a hundred miles wide and several hundred long, adding to the appearance of artificiality. Sometimes no canals are seen, but they come into view as the polar snows begin to melt; hence the suggestion that they really indicate great canals to carry off the water from the rapidly melting snow and distribute it by irrigation channels over the adjacent land, which, being rapidly covered with vegetation, causes the change of color which renders them visible. These observations were made by Mr. Percival Lowell during the favorable opposition, in 1894, at his observatory in Arizona, where the exceptional purity of the atmosphere renders it possible almost constantly to observe details which are elsewhere rarely visible. If future observations should confirm the views as to the artificial nature of these features of the surface of the planet which most nearly resembles our earth, it must be considered to be the most sensational astronomical discovery of the nineteenth century, and that which opens up the most exciting possibilities as to communication with beings who are sufficiently advanced to execute such widespread and gigantic irrigation works.

The ring around the planet Saturn was long supposed to be single, and to be solid like the planet itself; but with improved telescopes it was found to be double, and with still finer instruments to consist of an indefinite number of rings close together, one of them being very obscure, as if formed of nebulous matter. In the year 1859, Clerk-Maxwell, by a profound mathematical investigation, proved that either solid or liquid rings would be unstable, and would inevitably break up so as to form a number of satellites; and he concluded that the rings really consisted of a crowd of small bodies so near together as to appear like a solid mass; and as the appearance of the rings, and some slight changes detected in them, were in harmony with this view, it has been generally accepted. But quite recently the wonderful instrument, the spectroscope, has given the final demonstration that this theory is correct. If the rings are solid, it is clear that a point on the outer edge must move more rapidly than one on the inner edge; whereas, if they consist of separate particles, each revolving independently round

the planet, then, in accordance with the laws of all planetary motions, those forming the inner side of the rings, being nearer to the planet, must move much quicker than those on the outer side. As already explained, the spectroscope enables us to measure motion in the line of sight—that is, toward or away from us—of any heavenly bodies, and by observing the outer extremities of the rings to the right and left of the planet, where the motion is, of course, in these two directions, it is found that the motion of the inner edge is considerably more rapid than that of the outer edge, showing that those parts move round the planet independently, and are therefore formed of separate particles or small masses. These observations were made by the American astronomer, Professor James E. Keller, in 1895, and are of extreme delicacy; but that they are trustworthy is shown by the fact that the resulting velocities are in accordance with Kepler's third law, which determines the relative motions of all planetary bodies at varying distances from the primary.

A still more important discovery is that which has explained, by one consistent theory, the various phenomena presented by *aërolites*, fireballs, and shooting or falling stars, now generally classed as meteors and meteorites; and this theory is found to have an important bearing on the constitution of the solar system, and perhaps even on that of the whole stellar universe. Although there are records of the fall of solid stones from the sky in the works of classical, Chinese, and European authors, from 654 B. C. down to our times, while the astronomer Gassendi himself witnessed the fall of a stone weighing fifty-nine pounds in the year 1627, in the south of France, yet the phenomenon was so rare, and so inexplicable, that it was often disbelieved. One philosopher is reported to have disposed of the whole matter by saying, "There are no stones in the sky, therefore none can fall from it." But the evidence for such falls soon became overwhelming, and their connection with fireballs and shooting stars was also well established. One of the most remarkable of modern meteors was that seen at Aigle in Normandy, on April 26, 1803. About 1 P.M. a brilliant fireball was seen traversing the air at great speed. A violent ex-

plosion followed, apparently proceeding from a small lofty cloud. This was no doubt the product of the explosion which would be visible long before the sound was heard, and then came a perfect shower of stones, nearly three thousand being picked up, the largest weighing eight pounds. A still more extraordinary meteor was seen on March 19, 1719, about eight o'clock in the evening, in all parts of England, Scotland, and Ireland. Dr. Whiston, Newton's successor as professor of mathematics at Cambridge, who published an account of it, calculated its height over London as fifty-one miles, and over Devonshire thirty-nine miles.

EDITOR'S NOTE. — During the nineteenth century, by the use of the spectroscope and the development of the branch of astronomy known as astrophysics, man's knowledge of the heavens was extended widely. In the twentieth century continued research in the field of solar physics has led to a remarkable increase in our knowledge of the sun. At the Mount Wilson Observatory of the Carnegie Institution Professor George E. Hale with a remarkable instrumental equipment has been able to formulate much more definitely our ideas of the sun, and by direct observations to prove various theories as regards its general nature.

By a careful examination of the sun spots by means of the spectroscope and the spectroheliograph, it has been found that the sun spots are really electric vortices with a magnetic polarity corresponding to the direction of the whirl. These interesting discoveries followed the laboratory work of the Dutch physicist, Zeeman, that the spectrum of a luminous vapor would be affected by the presence of a strong magnetic field. The observations at Mount Wilson showed that the sun was a huge magnet having the same polarity as our earth, but about 80 times as powerful. Latterly the hypothesis has been advanced that radio-active phenomena are taking place in the sun and that the spontaneous disintegration of atoms is responsible for its heat.

ASTRONOMY

The Planet Mars

By SIR ROBERT BALL*

SEEING that the existence of intelligence is a characteristic feature of this earth, we feel naturally very much interested in the question as to whether there can be intelligent beings dwelling on other worlds around us. It is only regrettable that our means of solving this problem are so inadequate. Indeed, until quite lately it would have been almost futile to discuss this question at all. All that could then have been said on the subject amounted to little more than the statement that it would be intolerable presumption for man to suppose that he alone, of all beings in the universe, was endowed with intelligence, and that his insignificant little earth, alone amid the myriad globes of space, enjoyed the distinction of being the abode of life. Recent discovery has, however, given a new aspect to this question. At the end of the century certain observations were made disclosing features in the neighboring planet, Mars, which have riveted the attention of the world. On this question, above most others, extreme caution is necessary. It is especially the duty of the man of science to weigh carefully the evidence offered to him on a subject so important. He will test that evidence by every means in his power, and if he finds the evidence establishes certain conclusions, then he is bound to accept such conclusions irrespective of all other circumstances.

Mr. Percival Lowell has an observatory in an eminently fa-

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avorable position at Flagstaff, in Arizona. He has a superb telescope, and enjoys a perfect climate for astronomical work. Aided by skilful assistants, he has observed Mars under the most favorable circumstances with great care for some years. I must be permitted to say that, having carefully studied what Mr. Lowell has set forth, and having tested his facts and figures in every way in my power, most astronomers have come to the conclusion that, however astonishing his observations may seem to be, we cannot refuse to accept them.

No one has ever seen inhabitants on Mars, but Mr. Percival Lowell and one or two other equally favored observers have seen features on that planet which, so far as our experience goes, can be explained in no other way than by supposing that they were made by an intelligent designer for an intelligent purpose. Mr. Lowell has discovered that there are certain operations in progress on the surface of Mars which, if met with on this earth, we should certainly conclude, without the slightest hesitation, were the result of operations conducted under what we consider rational guidance.

A river, as Nature has made it, wends its way to and fro; it never takes the shortest route from one point to another; the width of the river is incessantly changing; sometimes it expands into a lake, sometimes it divides so as to inclose an island. If we could discern through our telescopes a winding line such as I have described on Mars it might perhaps represent a river.

But suppose, instead of a winding line, there was a perfectly straight line, or rather a great circle on the globe drawn as straight as a surveyor could lay it out—if we beheld an object like that on Mars I think we should certainly infer that it was not a river made in the ordinary course of natural operations; no natural river ever runs in that regular fashion. If such a straight line were indeed a river, then it must have been designedly straightened by human agency or by some other intelligent agency for some particular purpose. In its larger features Nature does not work by straight lines. A long and perfectly straight object, if found on our earth, might be a canal or it might be a road; it might be a railway or a terrace

of some kind; but assuredly no one would expect it to be a natural object.

We have the testimony of Schiaparelli, now strengthened by that of Mr. Lowell and his assistants, that there are many straight lines of this kind on Mars. They appear to be just as straight as a railway would have to be if laid across the flat and boundless prairie, where the engineer encountered no obstacle whatever to make him swerve from the direct path. These lines on Mars run for hundreds of miles, sometimes, indeed, I should say for thousands of miles. They are far wider than any terrestrial river, except perhaps the Amazon for a short part of its course. The lines on Mars are about forty miles wide. Indeed, the planet is so distant that if these lines were much narrower than forty miles they would be invisible. Each of them is marvelous in its uniformity throughout its entire length.

The existence of these straight lines on the planet contains perhaps the first suggestion of the presence of some intelligent beings on Mars. The mere occurrence of a number of perfectly straight, uniform lines on such a globe would in itself be a sufficiently remarkable circumstance. But there are other features exhibited by these objects which also suggest the astonishing surmise that they have been constructed by some intelligent beings for some intelligent purposes.

Sometimes two of these lines will start from a certain junction, sometimes there will be a third or a fourth from the same junction; in one case there are as many as seven radiating from the same point. Such an arrangement of these straight lines is certainly unlike anything that we find in Nature. We are led to seek for some other explanation of the phenomenon, and here is the explanation which Mr. Lowell offers:

It has recently been found that there are no oceans of water on the planet Mars. In earlier days it used no doubt to be believed that the dark marks easily seen in the telescope could represent nothing but oceans, but I think we must now give up the notion that these are watery expanses. Indeed, there is not much water on that globe anywhere in comparison with the abundance of water on our earth. It is the scarcity of

water which seems to give a clew to some of the mysteries discovered on Mars by Schiaparelli and Lowell.

As our earth moves round the sun we have, of course, the changing seasons of the year. In a somewhat similar manner Mars revolves around the sun, and accordingly this planet has also its due succession of seasons. There is a summer on Mars, and there is a winter; during the winter on that globe the poles of the planet are much colder than at other seasons, and the water there accumulates in the form of ice or snow to make those ice-caps that telescopic observers have so long noticed. In this respect Mars, of course, is like our earth. The ice-cap at each pole of our globe is so vast that even the hottest summer does not suffice to melt the accumulation; much of the ice and snow there remains to form the eternal snow which every arctic explorer so well knows. It would seem, however, that the contrast between winter and summer on Mars must be much more deeply marked than the contrast between winter and summer on our earth. During the summer of Mars ice and snow vanish altogether from the poles of that planet.

Mr. Lowell supposes that water is so scarce on Mars that the inhabitants have found it necessary to economize to the utmost whatever stock there may be of this most necessary element. The observations at Flagstaff tend to show that the dark lines on Mars mark the course of the canals by which the water melted in summer in the arctic regions is conducted over the globe to the tracts where the water is wanted. Not that the line as we see it represents actually the water itself; the straight line so characteristic of Mars's globe seems rather to correspond to the zones of vegetation which are brought into culture by means of water that flows along a canal in its center. In much the same way would the course of the Nile be exhibited to an inhabitant on Mars who was directing a telescope toward this earth: the river itself would not be visible, but the cultivated tracts which owe their fertility to the irrigation from the river would be broad enough to be distinguishable. The appearance of these irrigated zones would vary, of course, with the seasons; and we observe, as might have been expected,

changes in the lines on Mars corresponding to the changes in the seasons of the planet.

A noteworthy development of astronomy in the last century was the erection of mighty telescopes for the study of the heavens. It must here suffice to mention, as the latest and most remarkable of these, the famous instrument at the Yerkes Observatory, which belongs to the University of Chicago. Just as the century was drawing to its close, the Yerkes telescope began to enter on its sublime task of exhibiting the heavens under greater advantages than have ever been previously afforded to any astronomers since the world began.

When the University of Chicago was founded, it was desired to associate with the university an astronomical observatory which should be worthy of the astonishing place that this wonderful city has assumed in the world's history. Mr. Yerkes, an American millionaire, generously undertook to provide the cost of this observatory. Two noble disks of glass, forty inches in diameter, were produced at the furnaces of Messrs. Mantois, in Paris; these disks were worked by Mr. Alvan Clark, of Boston, into the famous object glass which, weighing nearly half a ton, has now been mounted in what we may describe as a temple or a palace such as had never been dreamed of before in the whole annals of astronomy.

ASTRONOMY

The Starry Heavens

By SIR ROBERT BALL

WE are about to discuss one of the grandest truths in the whole of nature. We have had occasion to see that this sun of ours is a magnificent globe immensely larger than the greatest of his planets, while the greatest of these planets is immensely larger than this earth; but now we are to learn that our sun is, indeed, only a star not nearly so bright as many of those which shine over our heads every night. We are comparatively close to the sun, so that we are able to enjoy his beautiful light and cheering heat. Each of those other myriads of stars is a sun, and the splendor of those distant suns is often far greater than that of our own. We are, however, so enormously far from them that they appear dwindled down to insignificance. To judge impartially between our sun or star and such a sun or star as Sirius we should stand half way between the two; it is impossible to make a fair estimate when we find ourselves situated close to one star and a million times as far from the other. After allowance is made for the imperfections of our point of view, we are enabled to realize the majestic truth that the sun is no more than a star, and that the other stars are no less than suns. This gives us an imposing idea of the extent and magnificence of the universe in which we are situated. Look up at the sky at night—you will see a host of stars; try to think that every one of them is itself a sun. It may probably be that those suns have planets circling round them, but it is hopeless for us to expect to see such planets. Were you standing on one of those stars and looking

toward our system, you would not perceive the sun to be the brilliant and gorgeous object that we know so well. If you could see him at all, he would merely seem like a star, not nearly as bright as many of those you can see at night. Even if you had the biggest of telescopes to aid your vision, you could never discern from one of these bodies the planets which surround the sun; no astronomer in the stars could see Jupiter, even if his sight were a thousand times as powerful as any sight or telescope that we know. So minute an object as our earth would, of course, be still more hopelessly beyond the possibility of vision.

THE NUMBER OF THE STARS

To count the stars involves a task which lies beyond the power of man to accomplish. Even without the aid of any telescope, we can see a great multitude of stars from this part of the world. There are also many constellations in the southern hemisphere which never appear above our horizon. If, however, we were to go to the equator, then, by waiting there for a twelvemonth, all the stars in the heavens would have been successively exposed to view. An astronomer, Houzeau, with the patience to count them, enumerated about six thousand. This is the naked-eye estimate of the star-population of the heavens; but if instead of relying on unaided vision, you get the assistance of a little telescope, you will be astounded at the enormous multitude of stars which are disclosed.

An ordinary opera-glass or binocular is a very useful instrument for looking at the stars in the heavens. If you employ an instrument of this sort, you will be amazed to find that the heavens teem with additional hosts of stars that your unaided vision would never have given you knowledge of. Any part of the sky may be observed; but, just to give an illustration, take one special region, namely, that of the Great Bear. Of these seven well-known stars, four form a sort of oblong, while the other three represent the tail. I would like you to make this little experiment. On a fine clear night, count how many stars there are within this oblong; they are all very faint, but you

will be able to see a few, and, with good sight, and on a clear night, you may see perhaps ten. Next take your opera-glass and sweep it over the same region; if you will carefully count the stars it shows, you will find fully two hundred; so that the opera-glass has, in this part of the sky, revealed nearly twenty times as many stars as could be seen without its aid. As 6,000 stars can be seen by the eye all over the heavens, we may fairly expect that twenty times that number—that is to say, 120,000 stars—could be shown by the opera-glass over the entire sky. Let us go a step further, and employ a telescope, the object-glass of which is three inches across. This is a useful telescope to have, and, if a good one, will show multitudes of pleasing objects, though an astronomer would not consider it very powerful. An instrument like this, small enough to be carried in the hand, has been applied to the task of enumerating the stars in the northern half of the sky, and 320,000 stars were counted. Indeed, the actual number that might have been seen with it is considerably greater, for when the astronomer Arge-lander made this memorable investigation he was unable to reckon many of the stars in localities where they lay very close together. This grand count only extended to half the sky, and, assuming that the other half is as richly inlaid with stars, we see that a little telescope like that we have supposed will, when swept over the heavens, reveal more than one hundred times as many stars as our eyes could possibly reveal. Still, we are only at the beginning of the count; the very great telescopes add largely to the number. There are multitudes of stars which in small instruments we cannot see, but which are distinctly visible from our great observatories. That telescope would be still but a comparatively small one which would show 6,000,000; and with the greatest instruments, the tale of stars has risen to over 50,000,000.

In addition to those stars which the largest telescopes show us, there are myriads which make their presence evident in a wholly different way. It is only in quite recent times that an attempt has been made to develop fully the powers of photography in representing the celestial objects. On a photographic plate which has been exposed to the sky in a great telescope

the stars are recorded by thousands. Many of these may, of course, be observed with a good telescope, but there are not a few others which no one ever saw in a telescope, which apparently no one ever could see, though the photograph is able to show them. We do not, however, employ a camera like that which the photographer uses who is going to take your portrait. The astronomer's plate is put into his telescope, and then the telescope is turned towards the sky. On that plate the stars produce their images, each by its own light. Some of these images are excessively faint, but we give a very long exposure of an hour or two hours; sometimes as much as four hours' exposure is given to a plate so sensitive that a mere fraction of a second would sufficiently expose it during the ordinary practice of taking a photograph in daylight.

We thus afford sufficient time to enable the fainter objects to indicate their presence upon the sensitive film. Even with an exposure of a single hour a picture exhibiting 16,000 stars has been taken. Yet the portion of the sky which it represents is only one ten-thousandth part of the entire heavens.

Here, at last, we have obtained some conception of the sublime scale on which the stellar universe is constructed. Yet even these plates cannot represent all the stars that the heavens contain. We have every reason for knowing that with larger telescopes, with more sensitive plates, with more prolonged exposures, ever fresh myriads of stars will be brought into our view.

You must remember that every one of these stars is truly a sun, a lamp, as it were, which doubtless gives light to other objects in its neighborhood as our sun sheds light upon this earth and the other planets. In fact, to realize the glories of the heavens you should try to think that the brilliant points you see are merely the luminous points of the otherwise invisible universe.

Standing one fine night on the deck of a Cunarder we passed in open ocean another great Atlantic steamer. The vessel was near enough for us to see not only the light from the mast-head but also the little beams from the several cabin ports; and we could see nothing of the ship herself. Her very existence was

only known to us by the twinkle of these lights. Doubtless her passengers could see, and did see, the similar lights from our own vessel, and they probably drew the correct inference that these lights indicated a great ship.

Consider the multiplicity of beings and objects in a ship: the captain and the crew, the passengers, the cabins, the engines, the boats, the rigging, and the stores. Think of all the varied interests there collected, and then reflect that out on the ocean, at night, the sole indication of the existence of this elaborate structure was given by the few beams of light that happened to radiate from it. Now raise your eyes to the stars; there are the twinkling lights. We cannot see what those lights illuminate, we can only conjecture what untold wealth of non-luminous bodies may also lie in their vicinity; we may, however, feel certain that just as the few gleaming lights from a ship are utterly inadequate to give a notion of the nature and the contents of an Atlantic steamer, so are the twinkling stars utterly inadequate to give even the faintest conception of the extent and the interest of the universe. We merely see self-luminous bodies, but of the multitudes of objects and the elaborate systems of which these bodies are only the conspicuous points we see nothing and we know very little. We are, however, entitled to infer from an examination of our own star—the sun—and of the beautiful system by which it is surrounded, that these other suns may be also splendidly attended. This is quite as reasonable a supposition as that a set of lights seen at night on the Atlantic Ocean indicates the existence of a fine ship.

THE CLUSTERS OF STARS

On a clear night you can often see, stretching across the sky, a track of faint light, which is known to astronomers as the “Milky Way.” It extends below the horizon, and then round the earth to form a girdle about the heavens. When we examine the Milky Way with a telescope we find, to our amazement, that it consists of myriads of stars, so small and so faint that we are not able to distinguish them individually; we merely see the glow produced from their collective rays. Remember-

ing that our sun is a star, and that the Milky Way surrounds us, it would almost seem as if our sun were but one of the host of stars which form this cluster.

There are also other clusters of stars, some of which are exquisitely beautiful telescopic spectacles. I may mention a celebrated pair of these objects which lies in the constellation of Perseus. The sight of them in a great telescope is so imposing that no one who is fit to look through a telescope could resist a shout of wonder and admiration when first they burst on his view. But there are other clusters, such as that which is known as the "Globular Cluster in the Centaur." It consists of a ball of stars, so far off that, however large these several suns may actually be, they have dwindled down to extremely small points of light. A homely illustration may serve to show the appearance which a globular cluster presents in a good telescope. Take a pepper-caster, and on a sheet of white paper, shake out the pepper until there is a little heap at the center and other grains are scattered loosely about. Imagine that every one of those grains of pepper was to be transformed into a tiny electric light, and then you have some idea of what a cluster of stars would look like when viewed through a telescope of sufficient power. There are multitudes of such groups scattered through the depths of space. They require our biggest telescopes to show them adequately. We have seen that our sun is a star, being only one of a magnificent cluster that forms the Milky Way. We have also seen that there are other groups scattered through the length and depth of space. It is thus we obtain a notion of the rank which our earth holds in the scheme of things celestial.

THE DISTANCES OF THE STARS

Now about the distances of the stars. I shall not make the attempt to explain fully how astronomers make such measurements, but I will give you some notion of how it is done. We make the two observations from two opposite points on the earth's orbit, which are therefore at a distance of 186,000,000 miles. Imagine that on Midsummer Day, when standing on the

earth here, I measured with a piece of card the angle between the star and the sun. Six months later on, on Midwinter Day, when the earth is at the opposite point of its orbit, I again measure the angle between the same star and the sun, and we can now determine the star's distance by making a triangle. I draw a line a foot long, and we will take this foot to represent 186,000,000 miles, the distance between the two stations; then placing the cards at the corners, I rule the two sides and complete the triangle, and the star must be at the remaining corner; then I measure the sides of the triangle, and how many feet they contain, and recollecting that each foot corresponds to 186,000,000 miles, we discover the distance of the star. If the stars were comparatively near us, the process would be a very simple one; but, unfortunately, the stars are so extremely far off that this triangle, even with a base of only one foot, must have its sides many miles long. Indeed, astronomers will tell you that there is no more delicate or troublesome work in the whole of their science than that of discovering the distance of a star.

In all such measurements we take the distance from the earth to the sun as a conveniently long measuring-rod, whereby to express the results. The nearest stars are still hundreds of thousands of times as far off as the sun. Let us ponder for a little on the vastness of these distances. We shall first express them in miles. Taking the sun's distance to be 93,000,000 miles, then the distance of the nearest fixed star is about twenty millions of millions of miles—that is to say, we express this by putting down a 2 first, and then writing thirteen ciphers after it. It is, no doubt, easy to speak of such figures, but it is a very different matter when we endeavor to imagine the awful magnitude which such a number indicates. I must try to give some illustrations which will enable you to form a notion of it. At first I was going to ask you to try and count this number, but when I found it would require at least 300,000 years, counting day and night without stopping, before the task was over, it became necessary to adopt some other method.

When on a visit in Lancashire I was once kindly permitted to visit a cotton mill, and I learned that the cotton yarn there

produced in a single day would be long enough to wind round this earth twenty-seven times at the equator. It appears that the total production of cotton yarn each day in all the mills together would be on the average about 155,000,000 miles. In fact, if they would only spin about one-fifth more, we could assert that Great Britain produced enough cotton yarn every day to stretch from the earth to the sun and back again! It is not hard to find from these figures how long it would take for all the mills in Lancashire to produce a piece of yarn long enough to reach from our earth to the nearest of the stars. If the spinners worked as hard as ever they could for a year, and if all the pieces were then tied together, they would extend to only a small fraction of the distance; nor if they worked for ten years, or for twenty years, would the task be fully accomplished. Indeed, upwards of four hundred years would be necessary before enough cotton could be grown in America and spun in this country to stretch over a distance so enormous. All the spinning that has ever yet been done in the world has not formed a long enough thread!

There is another way in which we can form some notion of the immensity of these sidereal distances. You will recollect that, when we were speaking of Jupiter's moons, I told you of the beautiful discovery which their eclipses enabled astronomers to make. It was thus found that light travels at the enormous speed of about 185,000 miles per second. It moves so quickly that within a single second a ray would flash two hundred times from London to Edinburgh and back again.

We said that a meteor travels one hundred times as swiftly as a rifle-bullet; but even this great speed seems almost nothing when compared with the speed of light, which is 10,000 times as great. Suppose some brilliant outbreak of light were to take place in a distant star—an outbreak which would be of such intensity that the flash from it would extend far and wide throughout the universe. The light would start forth on its voyage with terrific speed. Any neighboring star which was at a distance of less than 185,000 miles would, of course, see the flash within a second after it had been produced. More distant bodies would receive the intimation after intervals of

time proportioned to their distances. Thus, if a body were 1,000,000 miles away, the light would reach it in from five to six seconds, while over a distance as great as that which separates the earth from the sun the news would be carried in about eight minutes. We can calculate how long a time must elapse ere the light shall travel over a distance so great as that between the star and our earth. You will find that from the nearest of the stars the time required for the journey will be over three years. Ponder on all that this involves. That outbreak in the star might be great enough to be visible here, but we could never become aware of it till three years after it had happened. When we are looking at such a star to-night we do not see it as it is at present, for the light that is at this moment entering our eyes has traveled so far that it has been three years on the way. Therefore, when we look at the star now we see it as it was three years previously. In fact, if the star were to go out altogether, we might still continue to see it twinkling for a period of three years longer, because a certain amount of light was on its way to us at the moment of extinction, and so long as that light keeps arriving here, so long shall we see the star showing as brightly as ever. When, therefore, you look at the thousands of stars in the sky to-night, there is not one that you see as it is now, but as it was years ago.

I have been speaking of the stars that are nearest to us, but there are others much farther off. It is true we cannot find the distances of these more remote objects with any degree of accuracy, but we can convince ourselves how great that distance is by the following reasoning. Look at one of the brightest stars. Try to conceive that the object was carried away farther into the depths of space, until it was ten times as far from us as it is at present, it would still remain bright enough to be recognized in quite a small telescope; even if it were taken to one hundred times its original distance it would not have withdrawn from the view of a good telescope; while if it retreated one thousand times as far as it was at first it would still be a recognizable point in our mightiest instruments. Among the stars which we can see with our telescopes, we feel confident there must be many from which the light has expended hun-

dreds of years, or even thousands of years, on the journey. When, therefore, we look at such objects, we see them, not as they are now, but as they were ages ago; in fact, a star might have ceased to exist for thousands of years, and still be seen by us every night as a twinkling point in our great telescopes.

Remembering these facts, you will, I think, look at the heavens with a new interest. There is a bright star, Vega, or Alpha Lyræ, a beautiful gem, so far off that the light from it which now reaches our eyes started before many of my audience were born. Suppose that there are astronomers residing on worlds amid the stars, and that they have sufficiently powerful telescopes to view this globe, what do you think they would observe? They will not see our earth as it is at present; they will see it as it was years (and sometimes many years) ago. There are stars from which if England could now be seen, the whole of the country would be observed at this present moment to be in a great state of excitement at a very auspicious event. Distant astronomers might notice a great procession in London, and they could watch the coronation of the youthful queen, Queen Victoria, amid the enthusiasm of a nation. There are other stars still further, from which, if the inhabitants had good enough telescopes, they would now see a mighty battle in progress not far from Brussels. One splendid army could be beheld hurling itself time after time against the immovable ranks of the other. There can be no doubt that there are stars so far away that the rays of light which started from the earth on the day of the battle of Waterloo are only just arriving there. Farther off still, there are stars from which a bird's-eye view could be taken at this very moment of the signing of Magna Charta. There are even stars from which England, if it could be seen at all, would now appear, not as the great England we know, but as a country covered by dense forests, and inhabited by painted savages, who waged incessant war with wild beasts that roamed through the island. The geological problems that now puzzle us would be quickly solved could we only go far enough into space and had we only powerful enough telescopes. We should then be able to view our earth through the successive epochs of past geological time; we should be actu-

ally able to see those great animals whose fossil remains are treasured in our museums, tramping about over the earth's surface, splashing across its swamps, or swimming with broad flippers through its oceans. Indeed, if we could view our own earth reflected from mirrors in the stars, we might still see Moses crossing the Red Sea, or Adam and Eve being expelled from Eden.

DOUBLE STARS

Whenever you have a chance of looking at the heavens through a telescope, you should ask to be shown what is called a *double star*. There are many stars in the heavens which present no remarkable appearance to the unaided eye, but which a good telescope at once shows to be of quite a complex nature. These are what we call double stars, in which two quite distinct stars are placed so close together that the unaided eye is unable to separate them. Under the magnifying power of the telescope, however, they are seen to be distinct. In order to give some notion of what these objects are like, I shall briefly describe three of them. The first lies in that best known constellation, the Great Bear. If you look at his tail, which consists of three stars, you will see that near the middle one of the three a small star is situated; we call this little star Alcor, but it is the brighter one near Alcor to which I specially call your attention. The sharpest eye would never suspect that it was composed of two stars placed close together. Even a small telescope will, however, show this to be the case, and this is the easiest and the first observation that a young astronomer should make when beginning to turn a telescope to the heavens. Of course you will not imagine that I mean Alcor to be the second component of the double star; it is the bright star near Alcor which is the double. Here are two marbles, and these marbles are fastened an inch apart. You can see them, of course, to be separate; but if the pair were moved further and further away, then you would soon not be able to distinguish between them, though the actual distance between the marbles had not altered. Look at these two wax tapers which are now lighted; the little flames are an inch apart. You would have

to view them from a station a third of a mile away if the distance between the two flames were to appear the same as that between the two components of this double star. Your eye would never be able to discriminate between two lights only an inch apart at so great a distance; a telescope would, however, enable you to do so, and this is the reason why we have to use telescopes to show us double stars.

You might look at that double star year after year throughout the course of a long life without finding any appreciable change in the relative positions of its components. But we know that there is no such thing as rest in the universe; even if you could balance a body so as to leave it for a moment at rest, it would not stay there, for the simple reason that all the bodies round it in every direction are pulling at it, and it is certain that the pull in one direction will preponderate, so that move it must. Especially is this true in the case of two suns like those forming a double star. Placed comparatively near each other they could not remain permanently in that position; they must gradually draw together and come into collision with an awful crash. There is only one way by which such a disaster could be averted. That is by making one of these stars revolve around the other just as the earth revolves around the sun, or the moon revolves around the earth. Some motion must, therefore, be going on in every genuine double star, whether we have been able to see that motion or not.

Let us now look at another double star of a different kind. This time it is in the constellation of Gemini. The heavenly twins are called Castor and Pollux. Of these, Castor is a very beautiful double star, consisting of two bright points, a great deal closer together than were those in the Great Bear; consequently a better telescope is required for the purpose of showing them separately. Castor has been watched for many years, and it can be seen that one of these stars is slowly revolving around the other; but it takes a very long time, amounting to hundreds of years, for a complete circuit to be accomplished. This seems very astonishing, but when you remember how exceedingly far Castor is, you will perceive that that pair of stars which appear so close together that it requires

a telescope to show them apart must indeed be separated by hundreds of millions of miles. Let us try to conceive our own system transformed into a double star. If we took our outermost planet—Neptune—and enlarged him a good deal, and then heated him sufficiently to make him glow like a sun, he would still continue to revolve round our sun at the same distance, and thus a double star would be produced. An inhabitant of Castor who turned his telescope towards us would be able to see the sun as a star. He would not, of course, be able to see the earth, but he might see Neptune like another small star close to the sun. If generations of astronomers in Castor continued their observations of our system, they would find a binary star, of which one component took a century and a half to go round the other. Need we then be surprised that when we look at Castor we observe movements that seem very slow?

There is often so much diffused light about the bright stars seen in a telescope, and so much twinkling in some states of the atmosphere, that stars appear to dance about in rather a puzzling fashion, especially to one who is not accustomed to astronomical observations. I remember hearing how a gentleman once came to visit an observatory. The astronomer showed him Castor through a powerful telescope as a fine specimen of a double star, and then, by way of improving his little lesson, the astronomer mentioned that one of these stars was revolving around the other. "Oh, yes," said the visitor, "I saw them going round and round in the telescope." He would, however, have had to wait for a few centuries with his eye to the instrument before he would have been entitled to make this assertion.

Double stars also frequently delight us by giving beautifully contrasted colors. I dare say you have often noticed the red and the green lights that are used on railways in the signal lamps. Imagine one of those red and one of those green lights away far up in the sky and placed close together, then you would have some idea of the appearance that a colored double star presents, though perhaps I should add that the hues in the heavenly bodies are not so vividly different as are those which our railway people find necessary. There is a particularly

beautiful double star of this kind in the constellation of the Swan. You could make an imitation of it by boring two holes, with a red-hot needle, in a piece of card, and then covering one of these holes with a small bit of the topaz-colored gelatine with which Christmas crackers are made. The other star is to be similarly colored with blue gelatine. A slide made on this principle placed in the lantern gives a very good representation of these two stars on the screen. There are many other colored doubles besides this one; and, indeed, it is noteworthy that we hardly ever find a blue or a green star by itself in the sky; it is always as a member of one of these pairs.

WHAT THE STARS ARE MADE OF

Here is a piece of stone. If I wanted to know what it was composed of, I should ask a chemist to tell me. He would take it into his laboratory, and first crush it into powder, and then, with his test tubes, and with the liquids which his bottles contain, and his weighing scales, and other apparatus, he would tell all about it; there is so much of this, and so much of that, and plenty of this, and none at all of that. But now, suppose you ask this chemist to tell you what the sun is made of, or one of the stars. Of course, you have not a sample of it to give him; how, then, can he possibly find out anything about it? Well, he can tell you something, and this is the wonderful discovery that I want to explain to you. We now put down the gas and I kindle a brilliant red light. Perhaps some of those whom I see before me have occasionally ventured on the somewhat dangerous practice of making fireworks. If there is any boy here who has ever constructed sky-rockets, and put the little balls into the top which are to burn with such vivid colors when the explosion takes place, he will know that the substance which tinged that fire red must have been strontium. He will recognize it by the color; because strontium gives a red light which nothing else will give. Here are some of these lightning papers, as they are called; they are very pretty and very harmless; and these, too, give brilliant red flashes as I throw them. The red tint, has, no doubt, been produced by

strontium also. You see we recognized the substance simply by the color of the light it produced when burning.

There are, in nature, a number of simple bodies called elements. Every one of these, when ignited under suitable conditions, emits a light which belongs to it alone, and by which it can be distinguished from every other substance. Many of the materials will yield light which will require to be studied by much more elaborate artifices than those which have sufficed for us. But you will see that the method affords a means of finding out the actual substances present in the sun or in the stars. There is a practical difficulty in the fact that each of the heavenly bodies contains a number of different elements; so that in the light it sends us the hues arising from distinct substances are blended into one beam. The first thing to be done is to get some way of splitting up a beam of light, so as to discover the components of which it is made. You might have a skein of silks of different hues tangled together, and this would be like the sunbeam as we receive it in its unsorted condition. How shall we untangle the light from the sun or a star? I will show you by a simple experiment. Here is a beam from the electric light; beautifully white and bright, is it not? It looks so pure and simple, but yet that beam is composed of all sorts of colors mingled together, in such proportions as to form white light. I take a wedge-shaped piece of glass called a prism, and when I introduce it into the course of the beam, you see the transformation that has taken place. Instead of the white light you have now all the colors of the rainbow—red, orange, yellow, green, blue, indigo, violet. These colors are very beautiful, but they are transient, for the moment we take away the prism they all unite again to form white light. You see what the prism has done; it has bent all the light in passing through it; but it is more effective in bending the blue than the red, and consequently the blue is carried away much farther than the red. Such is the way in which we study the composition of a heavenly body. We take a beam of its light, we pass it through a prism, and immediately it is separated into its components; then we compare what we find with the lights given by the different elements, and thus we are enabled

to discover the substances which exist in the distant object whose light we have examined. I do not mean to say that the method is a simple one; all I am endeavoring to show is a general outline of the way in which we have discovered the materials present in the stars. The instrument that is employed for this purpose is called the spectroscope. And perhaps you may remember that name by these lines, which I have heard from an astronomical friend:—

“Twinkle, twinkle, little star,
Now we find out what you are,
When unto the midnight sky
We the spectroscope apply.”

I am sure it will interest everybody to know that the elements which the stars contain are not altogether different from those of which the earth is made. It is true there may be substances in the stars of which we know nothing here; but it is certain that many of the most common elements on the earth are present in the most distant bodies. I shall only mention one, the metal iron. That useful substance has been found in some of the stars which lie at almost incalculable distances from the earth.

THE NEBULÆ

I must say a few words about some dim and mysterious objects to which we have not yet alluded. They are what are called *nebulae*, or little clouds; and in one sense they are justly called little, for each of them occupies but a very small spot in the sky as compared with that which would be filled by an ordinary cloud in our air. The *nebulae* are, however, objects of the most stupendous proportions. Were our earth and thousands of millions of bodies quite as big all put together, they would not be nearly so great as one of these *nebulae*. Astronomers reckon up the various *nebulae* by thousands, but I must add that most of them are apparently faint and uninteresting. A *nebula* is sometimes liable to be mistaken for a comet. The comet is, as I have already explained, at once distinguished by the fact that it is moving and changing its appearance from

hour to hour, while scores of years elapse without changes in the aspect or position of a nebula. The most powerful telescopes are employed in observing these faint objects. A curious object in the constellation of Lyra can be seen under different telescopic powers. This is a gigantic ring of luminous gas. To judge of the size of this ring let us suppose that a railway were laid across it, and the train you entered at one side was not to stop until it reached the other side, how long do you think this journey would require? Let the train start at a speed of a mile a minute; you would think, surely, that it must soon cross the ring. But the minutes pass, an hour has elapsed; so the distance must be sixty miles at all events. The hours creep on into days, the days advance into years, and still the train goes on. The years would lengthen out into centuries, and even when the train had been rushing on for a thousand years with an unabated speed of a mile a minute the journey would certainly not have been completed. Nor do I venture to say what ages must elapse ere the terminus at the other side of the ring nebula would be reached.

A cluster of stars viewed in a small telescope will often seem like a nebula, for the rays of the stars become blended. A powerful telescope will, however, dispel the illusion and reveal the separate stars. It was, therefore, thought that all the *nebulæ* might be merely clusters so exceedingly remote that our mightiest instruments failed to resolve them into stars. But this is now known not to be the case. Many of these objects are really masses of glowing gas; such are, for instance, the ring *nebulæ*, of which I have just spoken.

ASTRONOMY

Comets

By CAMILLE FLAMMARION

THESE tailed bodies, which suddenly come to light up the heavens, were for long regarded with terror, like so many warning signs of Divine wrath. Men have always thought themselves much more important than they really are in the universal order; they have had the vanity to pretend that the whole creation was made for them, whilst in reality the whole creation does not suspect their existence. The earth we inhabit is only one of the smallest worlds, and therefore it can scarcely be for it alone that all the wonders of the heavens, of which the immense majority remains hidden from it, were created. In this disposition of man to see in himself the center and the end of everything, it was easy indeed to consider the steps of Nature as unfolded in his favor; and if some unusual phenomenon presented itself, it was considered to be without doubt a warning from Heaven. If these illusions had had no other result than the amelioration of the more timorous of the community one would regret these ages of ignorance; but not only were these fancied warnings of no use, seeing that, once the danger passed, man returned to his former state; but they also kept up among people imaginary terrors, and revived the fatal resolutions caused by the fear of the end of the world.

When one fancies the world is about to end—and this has been believed for more than a thousand years—no solicitude is felt in the work of improving this world; and, by the indifference or disdain into which one falls, periods of famine and general misery are induced which at certain times have overtaken

our community. Why use the wealth of a world which is going to perish? Why work, be instructed, or rise in the progress of the sciences or art? Much better to forget the world, and absorb one's self in the barren contemplation of an unknown life. It is thus that ages of ignorance weigh on man, and thrust him further and further into darkness, while science makes known, by its influence on the whole community, its great value and the magnitude of its aim.

The history of a comet would be an instructive episode of the great history of the heavens. In it could be brought together the description of the progressive movement of human thought, as well as the astronomical theory of these extraordinary bodies. Let us take, for example, one of the most memorable and best-known comets, and give an outline of its successive passages near the earth. Like the planetary worlds, comets belong to the solar system, and are subject to the rule of the Star King. It is the universal law of gravitation which guides their path; solar attraction governs them, as it governs the movement of the planets and the small satellites. The chief point of difference between them and the planets is, that their orbits are very elongated; and, instead of being nearly circular, they take the elliptical form. In consequence of the nature of these orbits, the same comet may approach very near the sun, and afterward travel from it to immense distances. Thus, the period of the comet of 1680 has been estimated at 3,000 years. It approaches the sun, so as to be nearer to it than our moon is to us, whilst it recedes to a distance eight hundred and fifty-three times greater than the distance of the earth from the sun. On the seventeenth of December, 1680, it was at its perihelion—that is, at its greatest proximity to the sun; it is now continuing its path beyond the Neptunian orbit. Its velocity varies according to its distance from the solar body. At its perihelion it travels thousands of leagues per minute; at its aphelion it does not pass over more than a few yards. Its proximity to the sun in its passage near that body caused Newton to think that it received a heat 28,000 times greater than that we experience at the summer solstice; and that this heat being 2,000 times greater than that of red-hot iron, an

iron globe of the same dimensions would be 50,000 years entirely losing its heat. Newton added that in the end comets will approach so near the sun that they will not be able to escape the preponderance of its attraction, and that they will fall one after the other into this brilliant body, thus keeping up the heat which it perpetually pours out into space. Such is the deplorable end assigned to comets by the author of the "*Principia*," an end which makes De la Brétonne say to Rétif: "An immense comet, already larger than Jupiter, was again increased in its path by being blended with six other dying comets. Thus displaced from its ordinary route by these slight shocks, it did not pursue its true elliptical orbit; so that the unfortunate thing was precipitated into the devouring center of the sun." "It is said," added he, "that the poor comet, thus burned alive, sent forth dreadful cries!"

It will be interesting, then, in a double point of view, to follow a comet in its different passages in sight of the earth. Let us take the most important in astronomical history—the one whose orbit has been calculated by Edmund Halley, and which was named after him. It was in 1682 that this comet appeared in its greatest brilliancy, accompanied with a tail which did not measure less than thirty-two millions of miles. By the observation of the path which it described in the heavens, and the time it occupied in describing it, this astronomer calculated its orbit, and recognized that the comet was the same as that which was admired in 1531 and 1607, and which ought to have reappeared in 1759. Never did scientific prediction excite a more lively interest. The comet returned at the appointed time; and on the twelfth of March, 1759, reached its perihelion. Since the year 12 before the Christian era, it had presented itself twenty-four times to the earth. It was principally from the astronomical annals of China that it was possible to follow it up to this period.

Its first memorable appearance in the history of France is that of 837, in the reign of Louis le Débonnaire. An anonymous writer of chronicles of that time, named "*The Astronomer*," gave the following details of this appearance, relative to the influence of the comet on the imperial imagination:

"During the holy days of the solemnization of Easter, a phenomenon ever fatal, and of gloomy foreboding, appeared in the heavens. As soon as the Emperor, who paid attention to these phenomena, received the first announcement of it, he gave himself no rest until he had called a certain learned man and myself before him. As soon as I arrived, he anxiously asked me what I thought of such a sign; I asked time of him, in order to consider the aspects of the stars, and to discover the truth by their means, promising to acquaint him on the morrow; but the Emperor, persuaded that I wished to gain time, which was true, in order not to be obliged to announce anything fatal to him, said to me: 'Go on the terrace of the palace and return at once to tell me what you have seen, for I did not see this star last evening, and you did not point it out to me; but I know that it is a comet; tell me what you think it announces to me.' Then, scarcely allowing me time to say a word, he added: 'There is still another thing you keep back; it is that a change of reign and the death of a prince are announced by this sign.' And as I advanced the testimony of the prophet, who said: 'Fear not the signs of the heavens as the nations fear them,' the prince with his grand nature, and the wisdom which never forsook him, said, 'We must not only fear Him who has created both us and this star. But as this phenomenon may refer to us, let us acknowledge it as a warning from Heaven.'"

Louis le Débonnaire gave himself and his court to fasting and prayer, and built churches and monasteries. He died three years later, in 840, and historians have profited by this slight coincidence to prove that the appearance of the comet was a harbinger of death. The historian, Raoul Glader, added later: "These phenomena of the universe are never presented to man without surely announcing some wonderful and terrible event."

Halley's comet again appeared in April, 1066, at the moment when William the Conqueror invaded England. It was pretended that it had the greatest influence on the fate of the battle of Hastings, which delivered over the country to the Normans.

A contemporary poet, alluding probably to the English

diadem with which William was crowned, had proclaimed in one place, "that the comet had been more favorable to William than nature had been to Cæsar; the latter had no hair, but William had received some from the comet." A monk of Malmesbury apostrophized the comet in these terms: "Here thou art again, thou cause of the tears of many mothers! It is long since I have seen thee, but I see thee now, more terrible than ever; thou threatenest my country with complete ruin!"

In 1455, the same comet made a more memorable appearance still. The Turks and Christians were at war, the West and the East seemed armed from head to foot—on the point of annihilating each other. The crusade undertaken by Pope Calixtus III. against the invading Saracens was waged with redoubled ardor on the sudden appearance of the star with the flaming tail. Mahomet II. took Constantinople by storm, and raised the siege of Belgrade. But the Pope having put aside both the curse of the comet and the abominable designs of the Mussulmans, the Christians gained the battle, and vanquished their enemies in a bloody fight. The *Angelus* to the sound of bells dates from these ordinances of Calixtus III. referring to the comet.

This ancient comet witnessed many revolutions in human history, at each of its appearances, even in its later ones, in 1682, 1759, 1835; it was also presented to the earth under the most diverse aspects, passing through a great variety of forms, from the appearance of a curved saber, as in 1456, to that of a misty head, as in its last visit. Moreover, this is not an exception to the general rule, for these mysterious stars have had the gift of exercising a power on the imagination which plunged it in ecstasy or trouble. Swords of fire, bloody crosses, flaming daggers, spears, dragons, fish, and other appearances of the same kind, were given to them in the Middle Ages and the Renaissance.

Comets like those of 1577 appear, moreover, to justify by their strange form the titles with which they are generally greeted. The most serious writers were not free from this terror. Thus, in a chapter on celestial monsters, the celebrated surgeon, Ambroise Paré, described the comet of 1528 under

the most vivid and frightful colors: "This comet was so horrible and dreadful that it engendered such great terror to the people, that they died, some with fear, others with illness. It appeared to be of immense length, and of blood color; at its head was seen the figure of a curved arm, holding a large sword in the hand as if it wished to strike. At the point of the sword there were three stars, and on either side was seen a great number of hatchets, knives, and swords covered with blood, amongst which were numerous hideous human faces, with bristling beards and hair."

The imagination has good eyes when it exerts itself. The great and strange variety of cometary aspects is described with exactitude by Father Souciet in his Latin poem on comets. "Most of them," says he, "shine with fires interlaced like thick hair, and from this they have taken the name of comets. One draws after it the twisted folds of a long tail; another appears to have a white and bushy beard; this one throws a glimmer similar to that of a lamp burning during the night; that one, O Titan! represents thy resplendent face; and this other, O Phoebe! the form of thy nascent horns. There are some which bristle with twisted serpents. Shall I speak of those armies which have sometimes appeared in the air? of those clouds which follow as it were along a circle, or which resemble the head of Medusa? Have there not often been seen figures of men or savage animals?

"Often, in the gloom of night, lighted up by these sad fires, the horrible sound of arms is heard, the clashing of swords which meet in the clouds, the ether furiously resounding with fearful din which crush the people with terror. All comets have a melancholy light, but they have not all the same color. Some have a leaden color; others that of flame or brass. The fires of some have the redness of blood; others resemble the brightness of silver. Some again are azure; others have the dark and pale color of iron. These differences come from the diversity of the vapors which surround them, or from the different manner in which they receive the sun's rays. Do you not see in our fires, that various kinds of wood produce different colors? Pines and firs give a flame mixed with thick smoke,

and throw out little light. That which rises from sulphur and thick bitumen is bluish. Lighted straw gives out sparks of a reddish color. The large olive, laurel, ash of Parnassus, etc., trees which always retain their sap, throw a whitish light similar to that of a lamp. Thus, comets whose fires are formed of different materials each take and preserve a color which is peculiar to them."

Instead of being a cause of fear and terror, the variety and variability of the aspect of comets ought rather to indicate to us the harmlessness of their nature.

GEOLOGY

The Glacial Epoch and Primitive Man

By ALFRED RUSSEL WALLACE

THE foundations of modern geology were laid, in the latter part of the last century, by Werner, Hutton, and William Smith, but most of the details and some of the more important principles have been wholly worked out during the present century. The great landmarks of its progress can alone be referred to here, namely (1) the establishment by Lyell of what has been termed the uniformitarian theory; (2) the proof of a recent glacial epoch and the working out of its effects upon the earth's surface; and (3) the discovery that man in the northern hemisphere lived contemporaneously with many now extinct animals.

In the early part of the century, and so late as the year 1830, Cuvier's "Essay on the Theory of the Earth" held the field as the exponent of geological theory. A fifth edition of the English translation appeared in 1827, and a German translation so late as 1830. In this work it was maintained that almost all geological phenomena pointed to a state of the earth and of natural forces very different from what now exists. In the raised beds of shells, in fractured rocks, in vertical stratification, we were said to have proofs "that the surface of the globe has been broken up by revolutions and catastrophes." The differences in the character of adjacent stratified deposits showed that there must have been various successive irruptions of the sea over the land; and Cuvier maintained that these irruptions and retreats of the sea were not slow or gradual, "but that most of the catastrophes which have occasioned them

have been sudden." He urged that the sharp and bristling ridges and peaks of the primitive mountains "are indications of the violent manner in which they have been elevated"; and he concludes that "it is in vain we search among the powers which now act at the surface of the earth for causes sufficient to produce the revolutions and catastrophes, the traces of which are exhibited in its crust." This theory of convulsions and catastrophes held almost universal sway within the memory of persons now living; for although Hutton and Playfair had advanced far more accurate views, they appear to have made little impression, while the great authority attached to Cuvier's name carried all before it.

But in 1830, while Cuvier was at the height of his fame, and his book was still being translated into foreign languages, a hitherto unknown writer published the first volume of a work which struck at the very roots of the catastrophe theory, and demonstrated, by a vast array of facts and the most cogent reasoning, that almost every portion of it was more or less imaginary and in opposition to the plainest teachings of nature. The victory was complete. From the date of the publication of the "*Principles of Geology*" there were no more English editions of "*The Theory of the Earth*."

Lyell's method was that of a constant appeal to the processes of nature. Before asserting that certain results could not be due to existing causes he carefully observed what those causes were now doing. He applied to them the tests of accurate measurement, and he showed that, taking into account the element of long-continued action, they were, in almost every case, fully adequate to explain the observed phenomena. He showed that modern volcanoes had poured out equally vast masses of melted rock, which had covered equally large areas, with any ancient volcano; that strata were now forming, comparable in extent and thickness with any ancient strata; that organic remains were being preserved in them, just as in the older formations; that land was almost everywhere either rising or sinking, as of old; that valleys were being excavated and mountains worn away; that earthquake shocks were producing faults in the rocks; that vegetation was now preparing future coal-beds;



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that limestones, sandstones, metamorphic and igneous rocks were still being formed; and that, given time, and the intermittent or continuous action of the causes we can now trace in operation, all the contortions and fractures of strata, all the ravines and precipices, and every other modification of the earth's crust supposed to imply the agency of sudden revolutions and violent catastrophes may be again and again produced.

During a period of more than forty years Sir Charles Lyell continued to enlarge and improve his work, bringing out eleven editions, the last of which was published three years before his death; and rarely has any scientific work so completely justified its title, since it remains to this day the best exposition of the "Principles of Geology"—the foundation on which the science itself must be and has been built. The disciples and followers of Lyell have been termed "Uniformitarians," on account of their belief that the causes which produced the phenomena manifested to us in the crust of the earth are essentially of the same nature as those acting now. And, as is often the case, the use of the term as a nickname has led to a misconception as to the views of those to whom it is applied. A few words on this point are therefore called for.

Modern objectors say that it is unphilosophical to maintain that in our little experience of a few hundred, or at most a few thousand, years, we can have witnessed all forms and degrees of the action of natural forces; that we have no right to take the historical period as a fair sample of all past geological ages; and that, as a mere matter of probability, we ought to expect to find proofs of greater earthquakes, more violent eruptions, more sudden upheavals, and more destructive floods, having occurred during the vast eons of past time. Now this argument is perfectly sound if limited to the occurrence of extreme cases, but not if applied to averages. No Uniformitarian will deny the probability of there having been *some* greater convulsions in past geological ages than have ever been experienced during the historical period. But modern convulsionists do not confine themselves to this alone, but maintain that, *as a rule*, all the great natural forces tending to modify the surface of the earth were more powerful and acted on a larger scale than they

do now. On the ground of mere probability, however, we have no right to assume a diminution rather than an increase of natural forces in recent times, unless there is some proof that these forces have diminished. Sir Charles Lyell shows that the cases adduced as indicating greater forces in the past are fallacious, and his doctrine is simply one of real as against imaginary forces.

But our modern objectors have another argument, founded upon the admitted fact that the earth has cooled and is slowly cooling, and was probably once in a molten condition. They urge that in early geological times, when the earth was hotter, the igneous, aqueous, and aerial forces were necessarily greater, and would produce more rapid changes and greater convulsions than now. This is a purely theoretical conclusion, by no means sure, and perhaps the very reverse of what really occurred. There are two reasons for this belief, which may be very briefly stated. After the earth's crust was once formed it cooled very slowly, and the crust became very gradually thicker. So far as the action of the molten interior on the crust may have produced convulsions they should become not less, but more violent as the crust becomes thicker. With a thin crust any internal tension will be more frequently relieved by fracture or bending, and the resulting disturbances will be *less* violent; but as the crust becomes thicker, internal tensions will accumulate, and when relieved by fracture the disturbance will be *more* violent.

As regards storms and other aerial disturbances, these also would probably be less violent when the temperature of the whole surface was more uniform as well as warmer, and the atmosphere consequently so full of vapor as to prevent the sun's rays from producing the great inequalities of temperature that now prevail. It is these inequalities that produce the great aerial disturbances of our era, which arise from the heated surfaces of the bare plains and deserts of the subtropical and warm temperate belts. In the equatorial belt (10° each side of the equator), where the heat is more uniform and the surface generally well clothed with vegetation, tornadoes and hurricanes are almost unknown.

There remains only the action of the tides upon coasts and estuaries, which may have been greater in early geological times, if, as is supposed, the moon was then considerably nearer to the earth than it is now. But this is a comparatively unimportant matter as regards geological convulsions, because its maximum effects recur at short intervals and with great regularity, so that both vegetation and the higher forms of animal life would necessarily be limited to the areas which were beyond its influence.

It thus appears that, so far from there being any theoretical necessity for greater violence of natural forces in early geological times, there are some weighty reasons why the opposite should have been the case; while all the evidence furnished by the rocks themselves, and by the contours of the earth's surface, are in favor of a general uniformity, with, of course, considerable local variability.

It is interesting to note the very different explanations of the commonest features of the earth's surface given by the old and by the new theories. In every mountain region of the globe deep valleys, narrow ravines, and lofty precipices are of common occurrence, and these were, by the old school, almost always explained as being due to convulsions of nature. In ravines, we were taught that the rocks had been "torn asunder," while the mountains and the precipices were indications of "sudden fractures and upheavals of the earth's crust." On the new theory, these phenomena are found to be almost wholly due to the slow action of the most familiar every-day causes, such as rain, snow, frost, and wind, with rivers, streams, and every form of running water, acting upon rocks of varying hardness, permeability, and solubility. Every shower of rain falling upon steep hillsides or gentle slopes, while partially absorbed, to a large extent runs over the surface, carrying solid matter from higher to lower levels. Every muddy stream or flooded river shows the effect of this action. Day and night, month after month, year after year, this denudation goes on, and its cumulative effects are enormous. The material is supplied from the solid rocks, fractured and decomposed by the agency of snow and frost or by mere variations of temperature,

and primarily by those interior earth movements which are continually cleaving, fissuring, and faulting the solid strata, and thus giving the superficial causes of denudation facilities for action. The amount and rate of this superficial erosion and denudation of the earth's surface can be determined by the quantity of solid matter carried down by the rivers to the sea. This has been measured with considerable accuracy for several important rivers; and by comparing the quantity of matter, both in suspension and solution, with the area of the river basin, we know exactly the average amount of lowering of the whole surface per annum. It has thus been calculated that

The Mississippi removes one foot of the surface of its basin in

					6,000 years
" Ganges	"	"	"	"	2,358 "
" Hoang Ho	"	"	"	"	1,464 "
" Rhône	"	"	"	"	1,528 "
" Danube	"	"	"	"	6,846 "
" Po	"	"	"	"	729 "
" Nith	"	"	"	"	4,723 "

The average of these rivers gives us one foot as the lowering of the land by sub-aerial denudation in 3,000 years, or a thousand feet in three million years; but as Europe has a mean altitude of less than a thousand feet, it follows that, at the present rate of denudation, the whole of Europe would be reduced to nearly the sea-level in about three million years. Before this method of measuring the rate of the lowering of continents was hit upon by Mr. Alfred Tylor in 1853, no one imagined that it was anything like so rapid; and, as a million years is certainly a short period as compared with the whole geological record, it is clear that elevation must, on the whole, have always kept pace with the two lowering agencies—sinking and denudation. Again, as in every continent the areas occupied by plains and lowlands, where denudation is comparatively slow, are large as compared with the mountain areas, where all the denuding agencies are most powerful, it is probable that most mountain ranges are being lowered at perhaps ten times the

above average rate, and many mountain peaks and ridges perhaps a hundred times.

Examples of the rapidity of denudation as compared with earth-movements are to be found everywhere. In disturbed regions, faults of many hundreds, and sometimes even thousands of feet, are not uncommon; yet there is often no inequality on the surface, indicating that the dislocation of strata has been caused by small and often-repeated movements, at such intervals that denudation has been able to remove the elevated portion as it arose. Again, when the strata are bent into great folds or undulations, it is only rarely that the tops of the folds correspond to ridges and the depressions to valleys. Frequently the reverse is the case, a valley running along the anticlinal line or structural ridge, while the synclinal or structural hollow forms a mountain top; while, in other cases, valleys cut across these structural features, with little or no regard to them. This results from the fact that it is not mountains or mountain ranges, as we see them, which have been raised by internal forces, but a considerable area, already perhaps much disturbed and dislocated by earth-movements, has been slowly raised till it became a kind of table-land. From its first elevation above the sea, however, it would have been exposed to rain-fall, and the water, flowing off in the direction of least resistance, would have formed a number of channels radiating from the highest portion, and thus establishing the first outlines of a system of valleys, which go on deepening as the land goes on rising, often quite irrespective of the nature of the rocks beneath. This explains the close resemblance in the general arrangement of valleys in all high regions, as well as the very common phenomenon of a river crossing the main range of a mountain system by a deep gorge; for this merely shows that what is now the highest part of the range was at first lower than that where the river has its source, but has become higher by the more rapid degradation of the lateral ranges, owing to their being formed of rock which is more easily disintegrated. The various peculiarities of open valley and narrow gorge, of sloping mountain-side or lofty precipice, of rivers cutting across hills, as in the South Downs and at Clifton, when open plains

by which they might apparently have reached the sea are near at hand, may be all explained as the results of those simple causes which are everywhere in action around us. It was Sir Charles Lyell who first convinced the whole scientific world of the efficacy of these familiar agents; and the secure establishment of this doctrine constitutes one of the great philosophical landmarks of the nineteenth century.

THE GLACIAL EPOCH

The proof of the recent occurrence in the north temperate zone of a glacial epoch, during which large portions of Europe and North America were buried in ice, may, from one point of view, be thought to prove that other agents than those now in operation have acted in past ages, and thus to disprove the main assumption of the Uniformitarians. But, on the other hand, its existence has been demonstrated by those very methods which Sir Charles Lyell advocated—the accurate observation of what nature is doing now; while an ice age really exists at the present time in Greenland, in the same latitude as nearly the whole of Sweden and Norway, which enjoy a comparatively mild climate.

The first clear statement of the evidence for a former ice age was given, in 1822, by a Swiss engineer named Venetz. He pointed out that, where the existing glaciers have retreated, the rocks which they had covered are often rounded, smoothed, and polished, or grooved and striated in the direction of the glacier's motion; and that, far away from any existing glaciers, there were to be seen rocks similarly rounded, polished, and striated; while there also existed old moraine heaps exactly similar to those formed at present; and that these phenomena extended as far as the Jura range, on the flanks of which there were numbers of huge blocks of stone, of a kind not found in those mountains, but exactly similar to the ancient rocks of the main Alpine chain. Hence, he concluded that glaciers formerly extended down the Rhône valley as far as the Jura, and there deposited those erratic blocks, the presence of which had puzzled all former observers.

Soon afterward, Charpentier and Agassiz devoted themselves to the study of the records left by the ancient glaciers; and from that time to the present a band of energetic workers in every part of the world have, by minute observation and reasoning, established the fact of the extension of glaciers, or ice-sheets, over a large portion of the north temperate zone; and have also determined the direction of their motion and the thickness of the ice in various parts of their course. These conclusions are now admitted by every geologist who has devoted himself to the subject, and are embodied in the various official geological surveys of the chief civilized countries; and as they constitute one of the most remarkable chapters in the past history of the globe, and especially as this great change of climate occurred during the period of man's existence on the earth, a brief sketch of the facts must be here given.

There are four main groups of phenomena which demonstrate the former existence of glaciers in areas where they are now absent: (1) Moraines, and glacial drifts or gravels; (2) Smoothed, rounded, or planed rocks; (3) Striæ, grooves, and furrows on rock-surfaces; (4) Erratics and perched blocks.

(1) Moraines are formed by all existing glaciers, consisting of the earth and rocks which fall upon the ice-rivers from the sides of the valleys through which they flow. The slow motion of the glacier carries these down with it, and they are deposited in great heaps where it melts. In some glaciers where the tributary valleys are numerous and the *débris* that falls upon the ice is abundant, the whole of the lower part of the glacier for many miles is so buried in it that the surface of the ice cannot be seen, and in these cases there will be a continuous moraine formed across the valley where the glacier terminates. The characteristics of moraines are, that they consist of varied materials, earth, gravel, and rocks of various sizes intermingled confusedly; and they often form mounds or ridges completely across a valley, except where the stream passes through it, while in other cases they extend laterally along the slopes of the hillsides, where, owing to the form of the valley, the glacier has shrunk laterally and left its lateral moraine behind it. In many cases huge blocks of rock rest on the very summit of a

moraine, or, in the case of lateral moraines, on the very edge of a precipice in positions where no known agency but ice could have deposited them. These are called "perched blocks." Drifts or glacial gravels are deposits of material similar to that forming the moraines, but spread widely over districts which have formerly been buried in ice. These are often partially formed of stiff clay, in which are embedded quantities of smoothed and striated stones; but the great characteristic of all these ice-products is that the materials are not stratified—that is, sorted according to their fineness or coarseness, as is always the case when deposited by water—but are mingled confusedly together, the large stones being scattered all through the mass, and usually being quite as abundant at the top as at the bottom of the deposit. Such deposits are to be found all over the north and northwest of our islands, and are often well exhibited in railway cuttings; and wherever they are well developed, and the materials of which they consist differ from those forming the underlying rocks, they are an almost infallible indication of the former existence of a glacier or ice-sheet.

(2) The smoothed and rounded rocks called in Switzerland *roches moutonnées*, from their resemblance at a distance to recumbent sheep, are present in almost all recently glaciated mountainous countries, especially where the rocks are very hard. They are to be seen in all the higher valleys of Wales, the Lake District, and Scotland, and on examination are found to consist often of the hardest and toughest rocks. In other cases the rock forming the bed of the valley is found to be planed off smooth, even when it consists of hard crystalline strata thrown up at a high angle, and which naturally weathers into a jagged or ridged surface.

(3) The smoothed rocks are often found to be covered with numerous striæ, deep grooves, or huge flutings, and these are almost always in one direction, which is that of the course of the glacier. They may often be traced in the same direction for miles, and do not change in harmony with the lesser inequalities of the valley, as they would certainly do had they been formed by water action. These striæ and smoothed rocks are often found hundreds or even thousands of feet above the floor

of the valley, and in many cases a definite line can be traced, above which the rocks are rugged and jagged, while below it they are more or less rounded, smooth, or polished.

(4) Erratic blocks are among the most widespread and remarkable indications of glacial action, and they were the first that attracted the attention of men of science. The great plains of Denmark, Prussia, North Germany, and Russia are strewn with large masses of granite and hard metamorphic rocks, and these rest either on glacial drift or on quite different rocks of Secondary or Tertiary age. In parts of North Germany they are so abundant as to hide the natural surface, and they are often piled up in irregular heaps forming hills of granite boulders covered with forests of pine, birch, and juniper. Many of these blocks are more than a thousand tons' weight, and almost all of them can be traced to the mountains of Scandinavia as their source. Many of the largest blocks have been carried furthest from the parent rock—a fact which is conclusive against their having been brought to their present position by the action of floods.

The most interesting and instructive erratic blocks are those found upon the slopes of the Jura, because they have been most carefully studied by Swiss and French geologists, and have all been traced to their sources in the Alpine chain. The Jura mountains consist wholly of Secondary limestones, and are situated opposite to the Bernese Alps, at a distance of about fifty miles. Along their slopes for a distance of a hundred miles, and extending from their base to a height of 2,000 feet above the Lake of Neuchâtel, are great numbers of rocks, some of them as large as houses, and always quite different from that of which the Jura range is formed. These have all been traced to their parent rocks in various parts of the course of the old glacier of the Rhône, and, what is even more remarkable, their distribution is such as to prove that they were conveyed by a glacier and not by floating ice during a period of submergence. The rocks and other *débris* that fall upon a glacier from the two sides of its main valley form distinct moraines upon its surface, and however far the glacier may flow, and however much it may spread out where the valley

widens, they preserve their relative position so that whenever they are deposited by the melting of the glacier, those that came from the north side of the valley will remain completely separated from those which came from the south side. It was this fact which convinced Sir Charles Lyell that the theory of floating ice, which he had first adopted, would not explain the distribution of the erratics, and he has given in his "*Antiquity of Man*" (4th ed., p. 344) a map showing the course of the blocks as they were conveyed on the surface of the glacier to their several destinations. Other blocks are found on the lower slopes of the Alpine chain toward Bern on one side and Geneva on the other, while the French geologists have traced them down the Rhône valley seventy miles from Geneva, and also more than twenty miles west of the Jura, thus proving that at the lowest portion of that chain the glacier flowed completely over it. In all these cases the blocks can be traced to a source corresponding to their position on the theory of glacier action. Some of these rocks have been carried considerably more than two hundred miles, proving that the old glacier of the Rhône extended to this enormous distance from its source.

In our own islands and in North America these various classes of evidence have been carefully studied, the direction of the glacial striæ everywhere ascertained, and all the more remarkable erratic blocks traced to their sources, with the result that the extent and thickness of the various glaciers and ice-sheets are well determined and the direction of motion of the ice ascertained. The conclusions arrived at are very extraordinary, and must be briefly indicated.

In Great Britain, during the earlier and later phases of the ice age, all the mountains of Scotland, the Lake District, and Wales produced their own glaciers, which flowed down to the sea. But at the time of the culmination of the Glacial Epoch the Scandinavian ice-sheet extended on the southeast till it filled up the Baltic Sea and spread over the plains of north-western Europe, and also filled up the North Sea, joining the glaciers of Scotland, forming with them a continuous ice-sheet from which the highest mountains alone protruded. At the same time this Scotch ice-sheet extended into the Irish Sea,

and united with the glaciers of the Lake District, Wales, and Ireland till almost continuous ice-sheets enveloped those countries also. Glacial striæ are found up to a height of 3,500 feet in Scotland and 2,500 feet in the Lake District and in Ireland; while the Isle of Man was completely overflowed, as shown by glacial striæ on the summit of its loftiest mountains. Erratics from Scandinavia are found in great quantities on Flamborough Head, mixed with others from the Lake District and Galloway, showing that two ice streams met here from opposite directions. Erratics from Scotland are also found in the Lake District, in North Wales, in the Isle of Man, and in Ireland, from which the direction of the moving ice can be determined. Great numbers of local rocks have also been carried into places far from their origin, and in every case this displacement is in the direction of the flow of the ice as ascertained by the other evidence—never in the opposite direction. Each great mountain area had, however, its own center of local dispersal, depending upon the position of greatest thickness of the ice-sheet, which was not necessarily that of the highest mountains, but was approximately the center of the main area of glaciation. Thus the center of the North Wales ice-sheet was not at Snowdon, but over the Arenig mountains, which thus became a local center of dispersal of erratics. In Ireland, the mountains being placed around the coasts, the great central plain became filled with ice which, continually accumulating, formed a huge dome of ice whose outward pressure caused motion in all directions till checked by the opposing motion of the great Scandinavian ice-sheet. This strange fact has been demonstrated by the work of the Irish Geological Survey and by many local geologists, and is universally accepted by all who have studied the evidence. The great outlines of the phenomena of the ice age in our islands are now as thoroughly well established as any of the admitted conclusions of geological science. In our own country the ice extended more or less completely over the whole of the midland counties and as far south as the Thames Valley.

When we cross the Atlantic the phenomena are equally remarkable. The whole of the northeastern United States and

Canada were also buried in an ice-sheet of enormous thickness and extent. It came southward as far as New York, and inland, in an irregular line, by Cincinnati, to St. Louis on the Mississippi. The whole of the region to the north of this line is covered with a deposit of drift, often of enormous thickness, while embedded in the drift, or scattered over its surface, are numbers of blocks and rock-masses, often formed of materials quite foreign to the bed-rock of the district. These erratics have in many cases been traced to their sources, sometimes six hundred miles away, and the study of these, and of the numerous grooved and striated rocks, show that the center of dispersal was far north of the Alleghanies and its outliers, and, as in the case of Ireland, must have consisted of a huge dome of ice situated over the plateau to the north of the Great Lakes, in what must have been an area of great snow-fall combined with a very low temperature. The maximum thickness of this great ice-sheet must have been at least a mile over a considerable portion of its area, as glacial deposits have been found on the summit of Mount Washington at an altitude of nearly 6,000 feet, and the center of motion was a considerable distance to the northwest, where it must have reached a still greater altitude.

The complete similarity of the conclusions reached by four different sets of observers in four different areas—Switzerland, northwestern Europe, the British Isles, and North America—after fifty years of continuous research, and after every other less startling theory had been put forth and rejected as wholly inconsistent with the phenomena to be explained, renders it as certain as any conclusion from indirect evidence can be, that a large portion of the north temperate zone, now enjoying a favorable climate and occupied by the most civilized nations of the world, was, at a very recent epoch, geologically speaking, completely buried in ice, just as Greenland is now. How recently the ice has passed away is shown by the perfect preservation of innumerable moraines, perched blocks, erratics, and glaciated rock-surfaces, showing that but little denudation has occurred to modify the surface; while undoubted relics of man found in glacial or interglacial deposits prove that it occurred

during the human period. It is clear that man could not have lived in any area while it was actually covered by the ice-sheet, while any indications of his presence at an earlier period would almost certainly be destroyed by the enormous abrading and grinding power of the ice.

Besides the areas above referred to, there are widespread indications of glaciation in parts of the world where a temperate climate now prevails. In the Pyrenees, Caucasus, Lebanon, and Himalayas glacial moraines are found far below the lower limits they now attain. In the Southern Hemisphere similar indications are found in New Zealand, Tasmania, and the southern portion of the Andes; but whether this cold period was coincident with that of the Northern Hemisphere we have at present no means of determining, nor even whether they were coincident among themselves, since it is quite conceivable that they may have been due to local causes, such as greater elevation of the land, and not to any general cause acting throughout the south temperate zone.

In the north temperate zone, however, the phenomena are so widespread and so similar in character, with only such modifications as are readily explained by proximity to, or remoteness from, the ocean, that we are almost sure they must have been simultaneous, and have been due to the same general causes, though perhaps modified by local changes in altitude and consequent modification of winds or ocean-currents. The time that has elapsed since the glaciation of the Northern Hemisphere passed away is, geologically, very small indeed, and has been variously estimated at from 20,000 to 100,000 years. At present the smaller period is most favored by geologists, but the duration of the ice age itself, including probably one or more inter-glacial mild periods, is admitted to be much longer, and probably to approach the higher figure above given.

The undoubted fact, however, that a large part of the north temperate zone has been recently subjected to so marvelous a change of climate, is of immense interest from many points of view. It teaches us in an impressive way how delicate is the balance of forces which renders what are now the most densely peopled areas habitable by man. We can hardly suppose that

even the tremendously severe ice age of which we have evidence is the utmost that can possibly occur; and, on the other hand, we may anticipate that the condition of things which in earlier geological times rendered even the polar regions adapted for a luxuriant woody vegetation may again recur, and thus vastly extend the area of our globe which is adapted to support human life in abundance and comfort. In the endeavor to account for the change of climate and of physical geography which brought about so vast a change, and then, after a period certainly approaching, and perhaps greatly exceeding, a hundred thousand years, caused it to pass away, some of the most acute and powerful intellects of our day have exerted their ingenuity; but, so far as obtaining general acceptance for the views of any one of them, altogether in vain. There seems reason to believe, however, that the problem is not an insoluble one; and when the true cause is reached, it will probably carry with it the long-sought datum from which to calculate with some rough degree of accuracy the duration of geological periods. But, whether we can solve the problem of its cause or no, the demonstration of the recent occurrence of a Glacial Epoch or Great Ice Age, with the determination of its main features over the Northern Hemisphere, will ever rank as one of the great scientific achievements of the nineteenth century.

THE ANTIQUITY OF MAN

Following the general acceptance of a glacial epoch by about twenty years, but to some extent connected with it, came the recognition that man had existed in Northern Europe along with numerous animals which no longer live there—the mammoth, the woolly rhinoceros, the wild horse, the cave-bear, the lion, the sabre-toothed tiger, and many others—and that he had left behind him, in an abundance of rude flint implements, the record of his presence. Before that time geologists, as well as the whole educated world, had accepted the dogma that man appeared upon the earth only when both its physical features and its animal and vegetable forms were exactly as we find them to-day; and this belief, resting solely on negative evi-

dence, was so strongly and irrationally maintained that the earlier discoveries could not get a hearing. A careful but enthusiastic French observer, M. Boucher de Perthes, had for many years collected with his own hands, from the great deposits of old river gravels in the valley of the Somme near Amiens, abundance of large and well-formed flint implements. In 1847 he published an account of them, but nobody believed his statements, till, ten years later, Dr. Falconer, and shortly afterward Professor Prestwich and Mr. John Evans, examined the collections and the places where they were found, and were at once convinced of their importance; and their testimony led to the general acceptance of the great antiquity of the human race. From that time researches on this subject have been carried on by many earnest students, and have opened up a number of altogether new chapters in human history.

So soon as the main facts were established, many old records of similar discoveries were called to mind, all of which had been ignored or explained away on account of the strong prepossession in favor of the very recent origin of man. In 1715 flint weapons had been found in excavations near Gray's Inn Lane, along with the skeleton of an elephant. In 1800 another discovery was made in Suffolk of flint weapons and the remains of extinct animals in the same deposits. In 1825 Mr. McEnery, of Torquay, discovered worked flints along with the bones and teeth of extinct animals in Kent's cavern. In 1840 a good geologist confirmed these discoveries, and sent an account of them to the Geological Society of London, but the paper was rejected as being too improbable for publication! All these discoveries were laughed at or explained away, as the glacial striæ and grooves so beautifully exhibited in the Vale of Llanberris were at first endeavored to be explained as the wheel-ruts caused by the chariots of the ancient Britons! These, combined with numerous other cases of the denial of facts on *a priori* grounds, have led me to the conclusion that, whenever the scientific men of any age disbelieve other men's careful observations without inquiry, the scientific men are *always* wrong.

Even after these evidences of man's great antiquity were
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admitted, strenuous efforts were made to minimize the time as measured by years; and it was maintained that man, although undoubtedly old, was entirely post-glacial. But evidence has been steadily accumulating of his existence at the time of the glacial epoch, and even before it; while two discoveries of recent date seem to carry back his age far into pre-glacial times. These are, first, the human cranium, bones, and works of art which have been found more than a hundred feet deep in the gold-bearing gravels of California, associated with abundant vegetable remains of extinct species, and overlaid by four successive lava streams from long extinct volcanoes. The other case is that of rude stone implements discovered by a geologist of the Indian Survey in Burma in deposits which are admitted to be of at least Pliocene age. In both these cases the evidence is disputed by some geologists, who seem to think that there is something unscientific, or even wrong, in admitting evidence that would prove the Pliocene age of any other animal to be equally valid in the case of man. There is assumed to be a great improbability of his existence earlier than the very end of the Tertiary epoch. But all the indications drawn from his relations to the anthropoid apes point to an origin far back in Tertiary time. For each one of the great apes—the gorilla, the chimpanzee, the orang, and even the gibbon—resemble man in certain features more than do their allies, while in other points they are less like him. Now, if man has been developed from a lower animal form, we must seek his ancestors not in the direct line between him and any of the apes, but in a line toward a common ancestor to them all; and this common ancestor must certainly date back to the early part of the Tertiary epoch, because in the Miocene period anthropoid apes not very different from living forms have been found fossil.

There is therefore no improbability whatever in the existence of man in the later portions of the Tertiary period, and we have no right, scientifically, to treat any evidence for his existence in any other way than the evidence for the existence of other animal types.

It has been argued by some writers that, as no other living species of mammal goes back farther than the Newer Pliocene,

therefore man is probably no older. But it is forgotten that the difference of man from the apes is not only specific but at least of generic or of family rank, while some naturalists place him even in a separate order of mammalia. Besides the erect posture and free hands, with all the details of anatomical structure which these peculiarities imply, the great development of his brain pre-eminently distinguishes him. We may suppose, therefore, that when he had reached the erect form, and possessed all the external appearance of man, his brain still remained undeveloped, and the time occupied by this development was not improbably equal to that required for the specific modification of the lower mammalia. It is often forgotten that so soon as man used fire and made weapons, all further useful modification would be in the direction of increased brain power, by which he was able to succeed both in his struggle against the elements and with the lower animals. There is therefore no improbability in finding the remains or the implements of a low type of man in the early Pliocene period.

The certainty that man coexisted with many now extinct animals, and the probability of our discovering his remains in undoubted Tertiary strata, constitute an immense advance on the knowledge and beliefs of our forefathers, and must therefore rank among the prominent features in the scientific progress of the nineteenth century.

GEOLOGY

Coal

By ELISHA GRAY

LONG ago, some man made the discovery that what we now call coal would burn and produce light and warmth. Who he was or how long ago he lived we do not know, but as all earthly things have a beginning, we know that such a man did live and that the discovery that coal would burn was made. Coal, in the sense that we use the word here, is not mentioned in the Scriptures. According to some authorities, coal was used in England as early as the ninth century. It is recorded that in 1259 King Henry III. granted a privilege to certain parties to mine coal at Newcastle. It is further stated that seven years after this time coal became an article of export. In 1306, coal was so generally used in London that a petition was sent to Parliament to have the use of it suppressed on the ground that it was a nuisance. Coal was used in Belgium, however, about 1200. There is a tradition that a blacksmith first used it in Liège as fuel. It was first used for manufacturing purposes about 1713.

Coal is found laid down in great veins, varying in thickness, in various parts of the world in the upper strata of the Paleozoic era. The age in which it was formed is called by geologists the Carboniferous (coal-bearing) age.

Before going on to account for the deposits of coal, let us stop a moment and consider what it is. Chemists tell us that coal is constructed chiefly of carbon, compounded with oxygen, hydrogen, and nitrogen. There are many varieties, but all may be classified under two general headings—bituminous and



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DRILLING AT THE BOTTOM OF A COAL MINE

anthracite. Bituminous coal contains a large amount of a tarry substance, a kind of mineral pitch or bitumen, which burns with a brilliant flame and a black sooty smoke, exceedingly rich in carbon. Anthracite coal is hard and stone-like in its texture, burning with scarcely any flame and no smoke. It produces a fire of intense heat when it is once ignited. There is another form of coal called cannel coal, which is a corruption of "candle coal," so called because a piece of this kind of coal when ignited will burn like a match or pine knot and give light like a candle. This is the richest of all the coal deposits in gases that are set free by heat, and for this reason is extensively used in the manufacture of what is commonly called coal gas. England produces a large amount of cannel coal, as well as another variety of bituminous coal, which latter, however, does not burn with such a black smoke as the coal found in the Ohio valley and the Western States of America. East of the Alleghany Mountains there is a region of anthracite coal that is very extensively worked and finds great favor in all parts of the country as fuel for domestic heating, especially on account of its great cleanliness.

All of the coal beds have a common origin, and the difference in the quality of coal found in different parts of the country is due to many circumstances, some of which have never been explained. There is indisputable proof, however, that all coal beds are of vegetable origin. Geologists tell us that these coal beds were formed during an age before the earth had cooled down to the temperature that it has at the present time—an age when vegetation was forced by the internal heat of the earth, instead of having to receive all its warmth from the sun's rays as we do now. Some of our readers are familiar with what is commonly termed a hot-bed. A hot-bed is made by putting soil on top of substances that will ferment and create heat underneath the soil. This heat from beneath will force vegetation and cause a much larger growth than there will be if left to the sun's rays alone. During the carboniferous age the earth was a great hot-bed.

The fossils of trees and plants, as well as reptiles, that we find in the great coal measures of the world, show that they

were of large tropical growth, and this is shown not only in the temperate zone, but in the zone farther north. For ages and ages this rank growth of vegetation grew up and fell down until a great layer of vegetable matter was formed, which at a later time was covered over by other strata of varied earth material, so that these great layers of vegetable formation were hermetically sealed and pressed down by an enormous weight that increased as time went on. The formation of coal may be studied even at this day (for it is now going on) by visiting and examining the great peat beds that are found in various parts of the world. It is well known that peat is used as a fuel by many people, especially the peasantry of the old countries. If peat is pressed to a sufficient degree of hardness it burns in a manner not unlike some forms of coal. Peat is a vegetable formation and has been formed by the rank growth of various kinds of vegetation in swampy places. Of course, it lacks the purity of the coal that was formed during the carboniferous age, because of the much slower growth of vegetation now than during that time, and the opportunity that peat bogs offer for an intermixture of earthy with the vegetable matter. The fact that we find the imprint of trees and ferns and other vegetable growth of tropical varieties, as well as the fossils of reptiles, imbedded in the coal measures, proves that at one time this stratum was at the land surface of the earth. We also find that all the formations of the Secondary and Tertiary periods are on top of the coal—and this shows that after the age of rank vegetable growth there was a sinking of the earth in many places far down into the ocean—so that vast layers of rock formed on top of these beds of vegetable matter. In England great chalk beds crop out in cliffs on the southern coast, and these chalk rocks are made up largely of the shells of marine animals. London stands on a chalk bed, from six hundred to eight hundred feet thick. Indeed, England has been poetically called Albion, White-land, from this appearance of her coast.

All of the great chalk beds were formed ages after the coal beds, as the latter are found in the upper strata of the Paleozoic period.

A study of these strata will show that there are many layers

of coal strata varying in thickness and separated by layers of shale and sandstone.

From the position that the coal measures occupy, being entirely under the Secondary and Tertiary formations, it will be observed that they are very old. If we should examine a piece of ordinary bituminous coal we should find that there are lines of cleavage in it parallel to each other, and that it is an easy matter to separate the lump on these lines. If we examine the outcrop of a coal bed we shall find that these lines of cleavage are horizontal. This indicates that the great bulk of vegetable matter of which the coal formation is made up has been subjected to tremendous pressure during a long period of time. If we further examine the structure of a body of coal we find the impressions of limbs and branches as well as the leaves of trees and various kinds of plants. We shall further find that these impressions lie in a plane in the same direction as the line of cleavage. This is a point to be remembered, as it helps to explain the nature and structure of other formations than those of coal. Not only are leaves and branches of vegetable matter found, but also fossils of reptiles, such as live on the land. Sometimes there is found the fossil of a great tree trunk standing in an erect position, with its roots running down into the rock below the coal bed, while the trunk extends upward entirely through the coal and high up into the other strata. All of these facts lead us to the firm conclusion that when the trees were grown that formed these beds, they were above the surface of the ocean. This, taken in connection with the fact that the vegetable fossils that are found indicate a tropical growth of great size, leads to the conclusion that the climate at the time these coal measures were formed was much warmer than it is now.

As already remarked, this extra warmth came from the earth itself before it had cooled down to its present temperature, rather than from the heat of the sun. There is nothing inconsistent in the thought that the sun may have been warmer in a former age than now. We may conceive that the earliest coal formations took place when the land stood above the surface of the water, and that the conditions were favorable for a

rapid and luxuriant growth of vegetation; after this had gone on for a very long period of time, by some convulsion of nature the land surface was submerged under the ocean, when other mineral substances were deposited on top of this layer of vegetable growth, which hardened into a rock formation. At a later period the earth was again elevated above the surface of the water and the same process of growth and decay was repeated. These oscillations of the earth up and down occurred at enormously long intervals, until all of the various coal strata with their intermediate formations were completed. After this we must suppose that the whole was submerged to a great depth and for a very long period of time, because of the great number and various kinds of rock formations laid down by water that lie on top of the coal measures. This tremendous weight, as it was gradually builded up, subjected these vegetable strata to an inconceivable pressure. In some places this pressure was much greater than in others, which undoubtedly is one of the reasons why we find such differences in the structure and quality of coal. There were, no doubt, many other reasons for differences, one of them being the character of the vegetable growth out of which they were formed. Again, in some parts of the world these coal strata may have been subjected to a considerable degree of heat, which would change the structure of the formation, and in some cases drive off the volatile gases. One can easily imagine that heat was thus a factor in the formation of what is known as anthracite coal, so much less gaseous than the bituminous kinds. The anthracite beds seem to be denser and of a more homogeneous character. The lines of cleavage are not so prominent, but there are the same evidences of vegetable origin that we find in the bituminous formations.

It will be seen from what has gone before that coal was first wood. But wood is a product of sunshine. Thus the sun was the architect and builder of the trees and plants that were finally hermetically sealed under the great earth strata. The sun gathered up the material and set in play the forces which made the chemical combinations of the various elements in nature that enter into vegetable growth.

After the lapse of untold ages of time, these great beds of stored-up sun-energy were discovered by man and their contents were dragged out to the earth's surface, to warm our houses, to drive the machinery of our factories, to send the locomotives flying across the continents and the steamships over the oceans. So important has this article become that if any one nation could control the output it would be able to paralyze all the navies and the manufacturing of the world.

If the coal of the world should become exhausted we should be confronted with a great problem. Fortunately for us, this is a problem that will have to be solved by the people of some future age, as the growth of wood will scarcely keep pace with the consumption of fuel. By that time the genius of man will have devised an economical means of storing the energy of the sunbeams directly for purposes of heat, light, and power.

GEOLOGY.

On a Piece of Chalk

By T. H. HUXLEY

IF a well were to be sunk at our feet in the midst of the English city of Norwich, the diggers would very soon find themselves at work in that white substance almost too soft to be called rock, with which we are all familiar as "chalk."

Not only here, but over the whole county of Norfolk, the well-sinker might carry his shaft down many hundred feet without coming to the end of the chalk; and, on the sea-coast, where the waves have pared away the face of the land which breasts them, the scarped faces of the high cliffs are often wholly formed of the same material. Northward, the chalk may be followed as far as Yorkshire; on the south coast it appears abruptly in the picturesque western bays of Dorset, and breaks into the Needles of the Isle of Wight; while on the shores of Kent it supplies that long line of white cliffs to which England owes her name of Albion.

Were the thin soil which covers it all washed away, a curved band of white chalk, here broader and there narrower, might be followed diagonally across England from Lulworth in Dorset, to Flamborough Head in Yorkshire—a distance of over two hundred and eighty miles as the crow flies.

From this band to the North Sea, on the east, and the Channel, on the south, the chalk is largely hidden by other deposits; but, except in the Weald of Kent and Sussex, it enters into the very foundation of all the southeastern counties.

Attaining, as it does in some places, a thickness of more

than a thousand feet, the English chalk must be admitted to be a mass of considerable magnitude. Nevertheless, it covers but an insignificant portion of the whole area occupied by the chalk formation of the globe, which has precisely the same general character as ours, and is found in detached patches, some less, and others more extensive, than the English.

Chalk occurs in Northwest Ireland; it stretches over a large part of France—the chalk which underlies Paris being, in fact, a continuation of that of the London basin; it runs through Denmark and Central Europe, and extends southward to North Africa; while eastward, it appears in the Crimea and in Syria, and may be traced as far as the shores of the Sea of Aral, in Central Asia.

If all the points at which true chalk occurs were circumscribed, they would lie within an irregular oval about three thousand miles in long diameter—the area of which would be as great as that of Europe, and would many times exceed that of the largest existing inland sea—the Mediterranean.

Thus the chalk is no unimportant element in the masonry of the earth's crust, and it impresses a peculiar stamp, varying with the conditions to which it is exposed, on the scenery of the districts in which it occurs. The undulating downs and rounded coombs, covered with sweet-grassed turf, of our inland chalk country, have a peacefully domestic and mutton-suggesting prettiness, but can hardly be called either grand or beautiful. But on our southern coasts, the wall-sided cliffs, many hundred feet high, with vast needles and pinnacles standing out in the sea, sharp and solitary enough to serve as perches for the wary cormorant, confer a wonderful beauty and grandeur upon the chalk headlands. And in the East, chalk has its share in the formation of some of the most venerable of mountain ranges, such as the Lebanon.

What is this widespread component of the surface of the earth? and whence did it come?

You may think this no very hopeful inquiry. You may not unnaturally suppose that the attempt to solve such problems as these can lead to no result, save that of entangling the

inquirer in vague speculations, incapable of refutation and of verification.

If such were really the case, I should have selected some other subject than "a piece of chalk" for my discourse. But, in truth, after much deliberation, I have been unable to think of any topic which would so well enable me to lead you to see how solid is the foundation upon which some of the most startling conclusions of physical science rest.

A great chapter of the history of the world is written in the chalk. Few passages in the history of man can be supported by such an overwhelming mass of direct and indirect evidence as that which testifies to the truth of the fragment of the history of the globe, which I hope to enable you to read, with your own eyes, to-night.

Let me add, that few chapters of human history have a more profound significance for ourselves. I weigh my words well when I assert, that the man who should know the true history of the bit of chalk which every carpenter carries about in his breeches' pocket, though ignorant of all other history, is likely, if he will think his knowledge out to its ultimate results, to have a truer, and therefore a better, conception of this wonderful universe, and of man's relation to it, than the most learned student who is deep-read in the records of humanity and ignorant of those of nature.

The language of the chalk is not hard to learn, not nearly so hard as Latin, if you only want to get at the broad features of the story it has to tell; and I propose that we now set to work to spell that story out together.

We all know that if we "burn" chalk, the result is quicklime. Chalk, in fact, is a compound of carbonic acid gas and lime; and when you make it very hot, the carbonic acid flies away and the lime is left.

By this method of procedure we see the lime, but we do not see the carbonic acid. If, on the other hand, you were to powder a little chalk and drop it into a good deal of strong vinegar, there would be a great bubbling and fizzing, and finally a clear liquid, in which no sign of chalk would appear. Here you see the carbonic acid in the bubbles; the lime, dissolved in the

vinegar, vanishes from sight. There are a great many other ways of showing that chalk is essentially nothing but carbonic acid and quicklime. Chemists enunciate the result of all the experiments which prove this, by stating that chalk is almost wholly composed of "carbonate of lime."

It is desirable for us to start from the knowledge of this fact, though it may not seem to help us very far toward what we seek. For carbonate of lime is a widely spread substance, and is met with under very various conditions. All sorts of limestones are composed of more or less pure carbonate of lime. The crust which is often deposited by waters which have drained through limestone rocks, in the form of what are called stalagmites and stalactites, is carbonate of lime. Or, to take a more familiar example, the fur on the inside of a tea-kettle is carbonate of lime; and, for anything chemistry tells us to the contrary, the chalk might be a kind of gigantic fur upon the bottom of the earth-kettle, which is kept pretty hot below.

Let us try another method of making the chalk tell us its own history. To the unassisted eye chalk looks simply like a very loose and open kind of stone. But it is possible to grind a slice of chalk down so thin that you can see through it—until it is thin enough, in fact, to be examined with any magnifying power that may be thought desirable. A thin slice of the fur of a kettle might be made in the same way. If it were examined microscopically, it would show itself to be a more or less distinctly laminated mineral substance, and nothing more.

But the slice of chalk presents a totally different appearance when placed under the microscope. The general mass of it is made up of very minute granules; but imbedded in this matrix are innumerable bodies, some smaller and some larger, but, on a rough average, not more than a hundredth of an inch in diameter, having a well-defined shape and structure. A cubic inch of some specimens of chalk may contain hundreds of thousands of these bodies, compacted together with incalculable millions of the granules.

The examination of a transparent slice gives a good notion of the manner in which the components of the chalk are

arranged, and of their relative proportions. But, by rubbing up some chalk with a brush in water and then pouring off the milky fluid, so as to obtain sediments of different degrees of fineness, the granules and the minute rounded bodies may be pretty well separated from one another, and submitted to microscopic examination, either as opaque or as transparent objects. By combining the views obtained in these various methods, each of the rounded bodies may be proved to be a beautifully constructed calcareous fabric, made up of a number of chambers, communicating freely with one another. The chambered bodies are of various forms. One of the commonest is something like a badly grown raspberry, being formed of a number of nearly globular chambers of different sizes congregated together. It is called *Globigerina*, and some specimens of chalk consist of little else than *Globigerinæ* and granules.

Let us fix our attention upon the *Globigerina*. If we can learn what it is and what are the conditions of its existence, we shall see our way to the origin and past history of the chalk.

A suggestion which may naturally enough present itself is, that these curious bodies are the result of some process of aggregation which has taken place in the carbonate of lime; that, just as in winter, the rime on our windows simulates the most delicate and elegantly arborescent foliage—proving that the mere mineral matter may, under certain conditions, assume the outward form of organic bodies—so this mineral substance, carbonate of lime, hidden away in the bowels of the earth, has taken the shape of these chambered bodies. I am not raising a merely fanciful and unreal objection. Very learned men, in former days, have even entertained the notion that all the formed things found in rocks are of this nature; and if no such conception is at present held to be admissible, it is because long and varied experience has now shown that mineral matter never does assume the form and structure we find in fossils. If any one were to try to persuade you that an oyster-shell (which is also chiefly composed of carbonate of lime) had crystallized out of sea-water, I suppose you would laugh at the absurdity. Your laughter would be justified by the fact that all

experience tends to show that oyster-shells are formed by the agency of oysters, and in no other way. And if there were no better reasons, we should be justified, on like grounds, in believing that *Globigerina* is not the product of anything but vital activity.

Happily, however, better evidence in proof of the organic nature of the *Globigerinæ* than that of analogy is forthcoming. It so happens that calcareous skeletons, exactly similar to the *Globigerinæ* of the chalk, are being formed, at the present moment, by minute living creatures, which flourish in multitudes, literally more numerous than the sands of the seashore, over a large extent of that part of the earth's surface which is covered by the ocean.

The history of the discovery of these living *Globigerinæ*, and of the part which they play in rock-building, is singular enough. It is a discovery which, like others of no less scientific importance, has arisen, incidentally, out of work devoted to very different and exceedingly practical interests.

When men first took to the sea, they speedily learned to look out for shoals and rocks; and the more the burden of their ships increased, the more imperatively necessary it became for sailors to ascertain with precision the depth of the waters they traversed. Out of this necessity grew the use of the lead and sounding-line; and, ultimately, marine surveying, which is the recording of the form of coasts and of the depth of the sea, as ascertained by the sounding-lead, upon charts.

At the same time, it became desirable to ascertain and to indicate the nature of the sea-bottom, since this circumstance greatly affects its goodness as holding ground for anchors. Some ingenious tar, whose name deserves a better fate than the oblivion into which it has fallen, attained this object by "arming" the bottom of the lead with a lump of grease, to which more or less of the sand or mud, or broken shells, as the case might be, adhered, and was brought to the surface. But, however well adapted such an apparatus might be for rough nautical purposes, scientific accuracy could not be expected from the armed lead, and to remedy its defects (especially when applied to sounding in great depths) Lieutenant Brooke, of the

American Navy, some years ago invented a most ingenious machine, by which a considerable portion of the superficial layer of the sea-bottom can be scooped out and brought up from any depth to which the lead descends.

In 1853, Lieutenant Brooke obtained mud from the bottom of the North Atlantic, between Newfoundland and the Azores, at a depth of more than 10,000 feet, or two miles, by the help of this sounding apparatus. The specimens were sent for examination to Ehrenberg of Berlin, and to Bailey of West Point, and those able microscopists found that this deep-sea mud was almost entirely composed of the skeletons of living organisms—the greater proportion of these being just like the *Globigerinæ* already known to occur in chalk.

Thus far, the work had been carried on simply in the interests of science, but Lieutenant Brooke's method of sounding acquired a high commercial value when the enterprise of laying down the telegraph-cable between this country and the United States was undertaken. For it became a matter of immense importance to know, not only the depth of the sea over the whole line along which the cable was to be laid, but the exact nature of the bottom, so as to guard against chances of cutting or fraying the strands of that costly rope. The Admiralty consequently ordered Captain Dayman, an old friend and shipmate of mine, to ascertain the depth over the whole line of the cable, and to bring back specimens of the bottom. In former days, such a command as this might have sounded very much like one of the impossible things which the young prince in the fairy tales is ordered to do before he can obtain the hand of the princess. However, in the months of June and July, 1857, my friend performed the task assigned to him with great expedition and precision, without, so far as I know, having met with any reward of that kind. The specimens of Atlantic mud which he procured were sent to me to be examined and reported upon.

The result of all these operations is, that we know the contours and the nature of the surface-soil covered by the North Atlantic, for a distance of 1,700 miles from east to west, as well as we know that of any part of the dry land.

It is a prodigious plain—one of the widest and most even plains in the world. If the sea were drained off, you might drive a wagon all the way from Valentia, on the west coast of Ireland, to Trinity Bay in Newfoundland. And, except upon one sharp incline about two hundred miles from Valentia, I am not quite sure that it would even be necessary to put the skid on, so gentle are the ascents and descents upon that long route. From Valentia the road would lie down-hill for about two hundred miles to the point at which the bottom is now covered by 1,700 fathoms of sea-water. Then would come the central plain, more than a thousand miles wide, the inequalities of the surface of which would be hardly perceptible, though the depth of water upon it now varies from 10,000 to 15,000 feet; and there are places in which Mont Blanc might be sunk without showing its peak above water. Beyond this, the ascent on the American side commences, and gradually leads, for about three hundred miles, to the Newfoundland shore.

Almost the whole of the bottom of this central plain (which extends for many hundred miles in a north and south direction) is covered by a fine mud, which, when brought to the surface, dries into a grayish white friable substance. You can write with this on a blackboard, if you are so inclined; and, to the eye, it is quite like very soft, grayish chalk. Examined chemically, it proves to be composed almost wholly of carbonate of lime; and if you make a section of it, in the same way as that of the piece of chalk was made, and view it with the microscope, it presents innumerable *Globigerinæ* embedded in a granular matrix.

Thus this deep-sea mud is substantially chalk. I say substantially, because there are a good many minor differences; but as these have no bearing on the question immediately before us—which is the nature of the *Globigerinæ* of the chalk—it is unnecessary to speak of them.

Globigerinæ of every size, from the smallest to the largest, are associated together in the Atlantic mud, and the chambers of many are filled by a soft animal matter. This soft substance is, in fact, the remains of the creature to which the *Globigerina* shell, or rather skeleton, owes its existence—and which is an

animal of the simplest imaginable description. It is, in fact, a mere particle of living jelly, without defined parts of any kind—without a mouth, nerves, muscles, or distinct organs, and only manifesting its vitality to ordinary observation by thrusting out and retracting from all parts of its surface long filamentous processes, which serve for arms and legs. Yet this amorphous particle, devoid of everything which, in the higher animals, we call organs, is capable of feeding, growing, and multiplying; of separating from the ocean the small proportion of carbonate of lime which is dissolved in sea-water; and of building up that substance into a skeleton for itself according to a pattern which can be imitated by no other known agency.

The notion that animals can live and flourish in the sea, at the vast depths from which apparently living *Globigerinæ* have been brought up, does not agree very well with our usual conceptions respecting the conditions of animal life; and it is not so absolutely impossible as it might at first appear to be, that the *Globigerinæ* of the Atlantic sea-bottom do not live and die where they are found.

As I have mentioned, the soundings from the great Atlantic plain are almost entirely made up of *Globigerinæ*, with the granules which have been mentioned, and some few other calcareous shells; but a small percentage of the chalky mud—perhaps at most some five per cent. of it—is of a different nature, and consists of shells and skeletons composed of siliceous bodies. These siliceous bodies belong partly to the lowly vegetable organisms which are called *Diatomaceæ*, and partly to the minute and extremely simple animals termed *Radiolaria*. It is quite certain that these creatures do not live at the bottom of the ocean, but at its surface—where they may be obtained in prodigious numbers by the use of a properly constructed net. Hence it follows that these siliceous organisms, though they are not heavier than the lightest dust, must have fallen, in some cases, through 15,000 feet of water, before they reached their final resting-place on the ocean floor. And, considering how large a surface these bodies expose in proportion to their weight, it is probable that they occupy a great length of time

in making their burial journey from the surface of the Atlantic to the bottom.

But if the Radiolaria and Diatoms are thus rained upon the bottom of the sea, from the superficial layer of its waters in which they pass their lives, it is obviously possible that the Globigerinæ may be similarly derived; and if they were so, it would be much more easy to understand how they obtain their supply of food than it is at present. Nevertheless, the positive and negative evidence all points the other way. The skeletons of the full-grown, deep-sea Globigerinæ are so remarkably solid and heavy in proportion to their surface as to seem little fitted for floating; and, as a matter of fact, they are not to be found along with the Diatoms and Radiolaria, in the uppermost stratum of the open ocean.

It has been observed, again, that the abundance of Globigerinæ, in proportion to other organisms of like kind, increases with the depth of the sea; and that deep-water Globigerinæ are larger than those which live in the shallower parts of the sea; and such facts negative the supposition that these organisms have been swept by currents from the shallows into the deeps of the Atlantic.

It therefore seems to be hardly doubtful that these wonderful creatures live and die at the depths in which they are found.

However, the important points for us are, that the living Globigerinæ are exclusively marine animals, the skeletons of which abound at the bottom of deep seas; and that there is not a shadow of reason for believing that the habits of the Globigerinæ of the chalk differed from those of the existing species. But if this be true, there is no escaping the conclusion that the chalk itself is the dried mud of an ancient deep sea.

In working over the soundings collected by Captain Dayman, I was surprised to find that many of what I have called the "granules" of that mud were not, as one might have been tempted to think at first, the mere powder and waste of Globigerinæ, but that they had a definite form and size. I termed these bodies "*coccoliths*," and doubted their organic nature. Dr. Wallich verified my observation, and added the interesting discovery that, not infrequently, bodies similar to these

"coccoliths" were aggregated together into spheroids, which he termed "*coccospheres*." So far as we knew, these bodies, the nature of which is extremely puzzling and problematical, were peculiar to the Atlantic soundings.

But, a few years ago, Mr. Sorby, in making a careful examination of the chalk by means of thin sections and otherwise, observed, as Ehrenberg had done before him, that much of its granular basis possesses a definite form. Comparing these formed particles with those in the Atlantic soundings, he found the two to be identical; and thus proved that the chalk, like the soundings, contains these mysterious coccoliths and coccospheres. Here was a further and a most interesting confirmation, from internal evidence, of the essential identity of the chalk with modern deep-sea mud. Globigerinæ, coccoliths, and coccospheres are found as the chief constituents of both, and testify to the general similarity of the conditions under which both have been formed.

The evidence furnished by the hewing, facing, and superposition of the stones of the Pyramids, that these structures were built by men, has no greater weight than the evidence that the chalk was built by Globigerinæ; and the belief that those ancient pyramid-builders were terrestrial and air-breathing creatures like ourselves, is not better based than the conviction that the chalk-makers lived in the sea.

But as our belief in the building of the Pyramids by men is not only grounded on the internal evidence afforded by these structures, but gathers strength from multitudinous collateral proofs, and is clinched by the total absence of any reason for a contrary belief; so the evidence drawn from the Globigerinæ that the chalk is an ancient sea-bottom, is fortified by innumerable independent lines of evidence; and our belief in the truth of the conclusion to which all positive testimony tends, receives the like negative justification from the fact that no other hypothesis has a shadow of foundation.

It may be worth while briefly to consider a few of these collateral proofs that the chalk was deposited at the bottom of the sea.

The great mass of the chalk is composed, as we have seen,

of the skeletons of *Globigerinæ*, and other simple organisms, imbedded in granular matter. Here and there, however, this hardened mud of the ancient sea reveals the remains of higher animals which have lived and died, and left their hard parts in the mud, just as the oysters die and leave their shells behind them in the mud of the present seas.

There are, at the present day, certain groups of animals which are never found in fresh waters, being unable to live anywhere but in the sea. Such are the corals; those corallines which are called *Polyzoa*; those creatures which fabricate the lamp-shells, and are called *Brachiopoda*; the pearly *Nautilus*, and all animals allied to it; and all the forms of sea-urchins and star-fishes.

Not only are all these creatures confined to salt water at the present day, but, so far as our records of the past go, the conditions of their existence have been the same: hence, their occurrence in any deposit is as strong evidence as can be obtained, that that deposit was formed in the sea. Now, the remains of animals of all the kinds which have been enumerated occur in the chalk, in greater or less abundance; while not one of those forms of shell-fish which are characteristic of fresh water has yet been observed in it.

When we consider that the remains of more than three thousand distinct species of aquatic animals have been discovered among the fossils of the chalk, that the great majority of them are of such forms as are now met with only in the sea, and that there is no reason to believe that any one of them inhabited fresh water—the collateral evidence that the chalk represents an ancient sea-bottom acquires as great force as the proof derived from the nature of the chalk itself. I think you will now allow that I did not overstate my case when I asserted that we have as strong grounds for believing that all the vast area of dry land at present occupied by the chalk was once at the bottom of the sea, as we have for any matter of history whatever; while there is no justification for any other belief.

No less certain is it that the time during which the countries we now call southeast England, France, Germany, Poland,

Russia, Egypt, Arabia, Syria, were more or less completely covered by a deep sea, was of considerable duration.

We have already seen that the chalk is, in places, more than a thousand feet thick. I think you will agree with me that it must have taken some time for the skeletons of the animalcules of a hundredth of an inch in diameter to heap up such a mass as that. I have said that throughout the thickness of the chalk the remains of other animals are scattered. These remains are often in the most exquisite state of preservation. The valves of the shell-fishes are commonly adherent; the long spines of some of the sea-urchins, which would be detached by the smallest jar, often remain in their places. In a word, it is certain that these animals have lived and died when the place which they now occupy was the surface of as much of the chalk as had then been deposited; and that each has been covered up by the layer of *Globigerina* mud, upon which the creatures imbedded a little higher up have, in like manner, lived and died. But some of these remains prove the existence of reptiles of vast size in the chalk sea. These lived their time, and had their ancestors and descendants, which assuredly implies time, reptiles being of slow growth. There is more curious evidence, again, that the process of covering up, or, in other words, the deposit of *Globigerina* skeletons, did not go on very fast. It is demonstrable that an animal of the cretaceous sea might die, that its skeleton might lie uncovered upon the sea-bottom long enough to lose all its outward coverings and appendages by putrefaction; and that, after this had happened, another animal might attach itself to the dead and naked skeleton, might grow to maturity, and might itself die before the calcareous mud had buried the whole.

Cases of this kind are admirably described by Sir Charles Lyell. He speaks of the frequency with which geologists find in the chalk a fossilized sea-urchin to which is attached the lower valve of a *Crania*. This is a kind of shell-fish, with a shell composed of two pieces, of which, as in the oyster, one is fixed and the other free.

“The upper valve is almost invariably wanting, though occasionally found in a perfect state of preservation in the white

chalk at some distance. In this case, we see clearly that the sea-urchin first lived from youth to age, then died and lost its spines, which were carried away. Then the young *Crania* adhered to the bared shell, grew and perished in its turn; after which, the upper valve was separated from the lower, before the *Echinus* became enveloped in chalky mud."

A specimen in the Museum of Practical Geology, in London, still further prolongs the period which must have elapsed between the death of the sea-urchin and its burial by the *Globigerinæ*. For the outward face of the valve of a *Crania*, which is attached to a sea-urchin (*Micraster*), is itself overrun by an incrusting coralline, which spreads thence over more or less of the surface of the sea-urchin. It follows that, after the upper valve of the *Crania* fell off, the surface of the attached valve must have remained exposed long enough to allow of the growth of the whole coralline, since corallines do not live imbedded in the mud.

The progress of knowledge may, one day, enable us to deduce from such facts as these the maximum rate at which the chalk can have accumulated, and thus to arrive at the minimum duration of the chalk period. Suppose that the valve of the *Crania* upon which a coralline has fixed itself in the way just described is so attached to the sea-urchin that no part of it is more than an inch above the face upon which the sea-urchin rests. Then, as the coralline could not have fixed itself if the *Crania* had been covered up with chalk-mud, and could not have lived had itself been so covered, it follows that an inch of chalk mud could not have accumulated within the time between the death and decay of the soft parts of the sea-urchin and the growth of the coralline to the full size which it has attained. If the decay of the soft parts of the sea-urchin; the attachment, growth to maturity, and decay of the *Crania*; and the subsequent attachment and growth of the coralline, took a year (which is a low estimate enough), the accumulation of the inch of chalk must have taken more than a year: and the deposit of a thousand feet of chalk must, consequently, have taken more than twelve thousand years.

The foundation of all this calculation is, of course, a knowl-

edge of the length of time the Crania and the coralline needed to attain their full size; and, on this head, precise knowledge is at present wanting. But there are circumstances which tend to show that nothing like an inch of chalk has accumulated during the life of a Crania; and, on any probable estimate of the length of that life, the chalk period must have had a much longer duration than that thus roughly assigned to it.

Thus, not only is it certain that the chalk is the mud of an ancient sea-bottom; but it is no less certain that the chalk sea existed during an extremely long period, though we may not be prepared to give a precise estimate of the length of that period in years. The relative duration is clear, though the absolute duration may not be definable. The attempt to affix any precise date to the period at which the chalk sea began or ended its existence, is baffled by difficulties of the same kind. But the relative age of the Cretaceous epoch may be determined with as great ease and certainty as the long duration of that epoch.

You will have heard of the interesting discoveries recently made, in various parts of Western Europe, of flint implements, obviously worked into shape by human hands, under circumstances which show conclusively that man is a very ancient denizen of these regions.

It has been proved that the old populations of Europe, whose existence has been revealed to us in this way, consisted of savages, such as the Esquimaux are now; that, in the country which is now France, they hunted the reindeer, and were familiar with the ways of the mammoth and the bison. The physical geography of France was in those days different from what it is now—the river Somme, for instance, having cut its bed a hundred feet deeper between that time and this; and it is probable that the climate was more like that of Canada or Siberia than that of Western Europe.

The existence of these people is forgotten even in the traditions of the oldest historical nations. The name and fame of them had utterly vanished until a few years back; and the amount of physical change which has been effected since their day renders it more than probable that, venerable as are some

of the historical nations, the workers of the chipped flints of Hoxne or of Amiens are to them, as they are to us, in point of antiquity.

But, if we assign to these hoar relics of long-vanished generations of men the greatest age that can possibly be claimed for them, they are not older than the drift, or boulder clay, which, in comparison with the chalk, is but a very juvenile deposit. You need go no further than your own seaboard for evidence of this fact. At one of the most charming spots on the coast of Norfolk, Cromer, you will see the boulder clay forming a vast mass, which lies upon the chalk, and must consequently have come into existence after it. Huge boulders of chalk are, in fact, included in the clay, and have evidently been brought to the position they now occupy by the same agency as that which has planted blocks of syenite from Norway side by side with them.

The chalk, then, is certainly older than the boulder clay. If you ask how much, I will again take you no further than the same spot upon your own coasts for evidence. I have spoken of the boulder clay and drift as resting upon the chalk. That is not strictly true. Interposed between the chalk and the drift is a comparatively insignificant layer, containing vegetable matter. But that layer tells a wonderful history. It is full of stumps of trees standing as they grew. Fir-trees are there with their cones, and hazel-bushes with their nuts; there stand the stools of oak and yew trees, beeches and alders. Hence this stratum is appropriately called the "forest-bed."

It is obvious that the chalk must have been upheaved and converted into dry land before the timber trees could grow upon it. As the bolls of some of these trees are from two to three feet in diameter, it is no less clear that the dry land thus formed remained in the same condition for long ages. And not only do the remains of stately oaks and well-grown firs testify to the duration of this condition of things, but additional evidence to the same effect is afforded by the abundant remains of elephants, rhinoceroses, hippopotamuses, and other great wild beasts, which it has yielded to the zealous search of such men as the Rev. Mr. Gunn.

When you look at such a collection as he has formed, and bethink you that these elephantine bones did veritably carry their owners about, and these great grinders crunch, in the dark woods of which the forest-bed is now the only trace, it is impossible not to feel that they are as good evidence of the lapse of time as the annual rings of the tree-stumps.

Thus there is a writing upon the wall of cliffs at Cromer, and whoso runs may read it. It tells us, with an authority which cannot be impeached, that the ancient sea-bed of the chalk sea was raised up, and remained dry land, until it was covered with forest, stocked with the great game whose spoils have rejoiced your geologists. How long it remained in that condition cannot be said; but "the whirligig of time brought its revenges" in those days as in these. That dry land, with the bones and teeth of generations of long-lived elephants, hidden away among the gnarled roots and dry leaves of its ancient trees, sank gradually to the bottom of the icy sea, which covered it with huge masses of drift and boulder clay. Sea-beasts, such as the walrus, now restricted to the extreme north, paddled about where birds had twittered among the topmost twigs of the fir-trees. How long this state of things endured we know not, but at last it came to an end. The upheaved glacial mud hardened into the soil of modern Norfolk. Forests grew once more, the wolf and the beaver replaced the reindeer and the elephant; and at length what we call the history of England dawned.

Thus you have, within the limits of your own county, proof that the chalk can justly claim a very much greater antiquity than even the oldest physical traces of mankind. But we may go further and demonstrate, by evidence of the same authority as that which testifies to the existence of the father of men, that the chalk is vastly older than Adam himself.

The Book of Genesis informs us that Adam, immediately upon his creation, and before the appearance of Eve, was placed in the garden of Eden. The problem of the geographical position of Eden has greatly vexed the spirits of the learned in such matters, but there is one point respecting which, so far as I know, no commentator has ever raised a doubt. This is, that

of the four rivers which are said to run out of it, Euphrates and Hiddekel are identical with the rivers now known by the names of Euphrates and Tigris.

But the whole country in which these mighty rivers take their origin, and through which they run, is composed of rocks which are either of the same age as the chalk, or of later date. So that the chalk must not only have been formed, but, after its formation, the time required for the deposit of these later rocks, and for their upheaval into dry land, must have elapsed, before the smallest brook which feeds the swift stream of "the great river, the river of Babylon," began to flow.

Thus, evidence which cannot be rebutted, and which need not be strengthened, though if time permitted I might indefinitely increase its quantity, compels you to believe that the earth, from the time of the chalk to the present day, has been the theater of a series of changes as vast in their amount as they were slow in their progress. The area on which we stand has been first sea and then land, for at least four alternations; and has remained in each of these conditions for a period of great length.

Nor have these wonderful metamorphoses of sea into land, and of land into sea, been confined to one corner of England. During the Chalk period, or "Cretaceous epoch," not one of the present great physical features of the globe was in existence. Our great mountain ranges Pyrenees, Alps, Himalayas, Andes, have all been upheaved since the chalk was deposited, and the cretaceous sea flowed over the sites of Sinai and Ararat.

All this is certain, because rocks of cretaceous or still later date have shared in the elevatory movements which gave rise to these mountain chains; and may be found perched up, in some cases, many thousand feet high upon their flanks. And evidence of equal cogency demonstrates that, though in Norfolk the forest-bed rests directly upon the chalk, yet it does so, not because the period at which the forest grew immediately followed that at which the chalk was formed, but because an immense lapse of time, represented elsewhere by thousands of feet of rock, is not indicated at Cromer.

I must ask you to believe that there is no less conclusive proof that a still more prolonged succession of similar changes occurred before the chalk was deposited. Nor have we any reason to think that the first term in the series of these changes is known. The oldest sea-beds preserved to us are sands, and mud, and pebbles, the wear and tear of rocks which were formed in still older oceans.

But, great as is the magnitude of these physical changes of the world, they have been accompanied by a no less striking series of modifications in its living inhabitants.

All the great classes of animals, beasts of the field, fowls of the air, creeping things, and things which dwell in the waters, flourished upon the globe long ages before the chalk was deposited. Very few, however, if any, of these ancient forms of animal life were identical with those which now live. Certainly not one of the higher animals was of the same species as any of those now in existence. The beasts of the field, in the days before the chalk, were not our beasts of the field, nor the fowls of the air such as those which the eye of man has seen flying, unless his antiquity dates infinitely further back than we at present surmise. If we could be carried back into those times, we should be as one suddenly set down in Australia before it was colonized. We should see mammals, birds, reptiles, fishes, insects, snails, and the like, clearly recognizable as such, and yet not one of them would be just the same as those with which we are familiar, and many would be extremely different.

From that time to the present, the population of the world has undergone slow and gradual, but incessant, changes. There has been no grand catastrophe—no destroyer has swept away the forms of life of one period, and replaced them by a totally new creation; but one species has vanished and another has taken its place; creatures of one type of structure have diminished, those of another have increased, as time has passed on. And thus, while the differences between the living creatures of the time before the chalk and those of the present day appear startling, if placed side by side, we are led from one to the other by the most gradual progress, if we follow the course

of Nature through the whole series of those relics of her operations which she has left behind.

And it is by the population of the chalk sea that the ancient and the modern inhabitants of the world are most completely connected. The groups which are dying out flourish, side by side, with the groups which are now the dominant forms of life.

Thus the chalk contains remains of those flying and swimming reptiles, the pterodactyl, the ichthyosaurus, and the plesiosaurus, which are found in no later deposits, but abounded in preceding ages. The chambered shells called ammonites and belemnites, which are so characteristic of the period preceding the cretaceous, in like manner die with it.

But, among these fading reminders of a previous state of things, are some very modern forms of life, looking like Yankee peddlers among a tribe of red Indians. Crocodiles of modern type appear; bony fishes, many of them very similar to existing species, almost supplant the forms of fish which predominate in more ancient seas; and many kinds of living shell-fish first become known to us in the chalk. The vegetation acquires a modern aspect. A few living animals are not even distinguishable as species from those which existed at that remote epoch. The *Globigerina* of the present day, for example, is not different specifically from that of the chalk; and the same may be said of many other Foraminifera. I think it probable that critical and unprejudiced examination will show that more than one species of much higher animals have had a similar longevity; but the only example which I can at present give confidently is the snake's-head lamp-shell (*Terebratulina caput serpentis*), which lives in our English seas and abounded (as *Terebratulina striata* of authors) in the chalk.

The longest line of human ancestry must hide its diminished head before the pedigree of this insignificant shell-fish. We Englishmen are proud to have an ancestor who was present at the battle of Hastings. The ancestors of *Terebratulina caput serpentis* may have been present at a battle of Ichthyosauria in that part of the sea which, when the chalk was forming, flowed over the site of Hastings. While all around has changed, this *Terebratulina* has peacefully propagated its species from gener-

ation to generation, and stands to this day as a living testimony to the continuity of the present with the past history of the globe.

Up to this moment I have stated, so far as I know, nothing but well-authenticated facts, and the immediate conclusions which they force upon the mind.

But the mind is so constituted that it does not willingly rest in facts and immediate causes, but seeks always after a knowledge of the remoter links in the chain of causation.

Taking the many changes of any given spot of the earth's surface, from sea to land, and from land to sea, as an established fact, we cannot refrain from asking ourselves how these changes have occurred. And when we have explained them—as they must be explained—by the alternate slow movements of elevation and depression which have affected the crusts of the earth, we go still further back, and ask, Why these movements?

I am not certain that any one can give you a satisfactory answer to that question. Assuredly I cannot. All that can be said for certain is, that such movements are part of the ordinary course of nature, inasmuch as they are going on at the present time. Direct proof may be given, that some parts of the land of the northern hemisphere are at this moment insensibly rising and others insensibly sinking; and there is indirect but perfectly satisfactory proof, that an enormous area now covered by the Pacific has been deepened thousands of feet since the present inhabitants of that sea came into existence.

Thus there is not a shadow of a reason for believing that the physical changes of the globe, in past times, have been effected by other than natural causes.

Is there any more reason for believing that the concomitant modifications in the forms of the living inhabitants of the globe have been brought about in any other way?

Before attempting to answer this question, let us try to form a distinct mental picture of what has happened in some special case.

The crocodiles are animals which, as a group, have a very

vast antiquity. They abounded ages before the chalk was deposited; they throng the rivers in warm climates at the present day. There is a difference in the form of the joints of the backbone, and in some minor particulars, between the crocodiles of the present epoch and those which lived before the chalk; but, in the Cretaceous epoch, as I have already mentioned, the crocodiles had assumed the modern type of structure. Notwithstanding this, the crocodiles of the chalk are not identically the same as those which lived in the times called "older tertiary," which succeeded the Cretaceous epoch; and the crocodiles of the older tertiaries are not identical with those of the newer tertiaries, nor are these identical with existing forms. I leave open the question whether particular species may have lived on from epoch to epoch. But each epoch has had its peculiar crocodiles; though all, since the chalk, have belonged to the modern type, and differ simply in their proportions and in such structural particulars as are discernible only to trained eyes.

How is the existence of this long succession of different species of crocodiles to be accounted for?

Only two suppositions seem to be open to us—either each species of crocodile has been specially created, or it has arisen out of some preëxisting form by the operation of natural causes.

Choose your hypothesis; I have chosen mine. I can find no warranty for believing in the distinct creation of a score of successive species of crocodiles in the course of countless ages of time. Science gives no countenance to such a wild fancy; nor can even the perverse ingenuity of a commentator pretend to discover this sense, in the simple words in which the writer of Genesis records the proceeding of the fifth and sixth days of the Creation.

On the other hand, I see no good reason for doubting the necessary alternative, that all these varied species have been evolved from preëxisting crocodilian forms by the operation of causes as completely a part of the common order of nature as those which have effected the changes of the inorganic world.

Few will venture to affirm that the reasoning which applies to crocodiles loses its force among other animals or among

plants. If one series of species has come into existence by the operation of natural causes, it seems folly to deny that all may have arisen in the same way.

A small beginning has led us to a great ending. If I were to put the bit of chalk with which we started into the hot but obscure flame of burning hydrogen, it would presently shine like the sun. It seems to me that this physical metamorphosis is no false image of what has been the result of our subjecting it to a jet of fervent, though nowise brilliant, thought to-night. It has become luminous, and its clear rays, penetrating the abyss of the remote past, have brought within our ken some stages of the evolution of the earth. And in the shifting "without haste, but without rest," of the land and sea, as in the endless variation of the forms assumed by living beings, we have observed nothing but the natural product of the forces originally possessed by the substance of the universe.

GEOLOGY

Volcanoes

By JEAN LOUIS RODOLPHE AGASSIZ

FIRST-BORN among the continents, though so much later in culture and civilization than some of more recent birth, America, so far as her physical history is concerned, has been falsely denominated the *New World*. Hers was the first dry land lifted out of the waters, hers the first shore washed by the ocean that enveloped all the earth beside; and while Europe was represented only by islands rising here and there above the sea, America already stretched an unbroken line of land from Nova Scotia to the Far West.

In the present state of our knowledge, our conclusions respecting the beginning of the earth's history, the way in which it took form and shape as a distinct, separate planet, must, of course, be very vague and hypothetical. Yet the progress of science is so rapidly reconstructing the past that we may hope to solve even this problem; and to one who looks upon man's appearance upon the earth as the crowning work in a succession of creative acts, all of which have had relation to his coming in the end, it will not seem strange that he should at last be allowed to understand a history which was but the introduction to his own existence. It is my belief that not only the future, but the past also, is the inheritance of man, and that we shall yet conquer our lost birthright.

Even now our knowledge carries us far enough to warrant the assertion that there was a time when our earth was in a state of igneous fusion, when no ocean bathed it and no atmosphere surrounded it, when no wind blew over it and no rain fell

upon it, but an intense heat held all its materials in solution. In those days the rocks which are now the very bones and sinews of our mother Earth—her granites, her porphyries, her basalts, her syenites—were melted into a liquid mass. As I am writing for the unscientific reader, who may not be familiar with the facts through which these inferences have been reached, I will answer here a question which, were we talking together, he might naturally ask in a somewhat skeptical tone. How do you know that this state of things ever existed, and, supposing that the solid materials of which our earth consists were ever in a liquid condition, what right have you to infer that this condition was caused by the action of heat upon them? I answer, Because it is acting upon them still; because the earth we tread is but a thin crust floating on a liquid sea of molten materials; because the agencies that were at work then are at work now, and the present is the logical sequence of the past. From artesian wells, from mines, from geysers, from hot springs, a mass of facts has been collected, proving incontestably the heated condition of all substances at a certain depth below the earth's surface; and if we need more positive evidence, we have it in the fiery eruptions that even now bear fearful testimony to the molten ocean seething within the globe and forcing its way out from time to time. The modern progress of geology has led us by successive and perfectly connected steps back to a time when what is now only an occasional and rare phenomenon was the normal condition of our earth; when the internal fires were enclosed by an envelope so thin that it opposed but little resistance to their frequent outbreak, and they constantly forced themselves through this crust, pouring out melted materials that subsequently cooled and consolidated on its surface. So constant were these eruptions, and so slight was the resistance they encountered, that some portions of the earlier rock-deposits are perforated with numerous chimneys, narrow tunnels as it were, bored by the liquid masses that poured out through them and greatly modified their first condition.

The question at once suggests itself, How was even this thin crust formed? what should cause any solid envelope, how-

ever slight and filmy when compared to the whole bulk of the globe, to form upon the surface of such a liquid mass? At this point of the investigation the geologist must appeal to the astronomer; for in this vague and nebulous border-land, where the very rocks lose their outlines and flow into each other, not yet specialized into definite forms and substances—there the two sciences meet. Astronomy shows us our planet thrown off from the central mass of which it once formed a part, to move henceforth in an independent orbit of its own. That orbit, it tells us, passed through celestial spaces cold enough to chill this heated globe, and of course to consolidate it externally. We know, from the action of similar causes on a smaller scale and on comparatively insignificant objects immediately about us, what must have been the effect of this cooling process upon the heated mass of the globe. All substances when heated occupy more space than they do when cold. Water, which expands when freezing, is the only exception to this rule. The first effect of cooling the surface of our planet must have been to solidify it, and thus to form a film or crust over it. That crust would shrink as the cooling process went on; in consequence of the shrinking, wrinkles and folds would arise upon it, and here and there, where the tension was too great, cracks and fissures would be produced. In proportion as the surface cooled, the masses within would be affected by the change of temperature outside of them, and would consolidate internally also, the crust gradually thickening by this process.

But there was another element without the globe, equally powerful in building it up. Fire and water wrought together in this work, if not always harmoniously, at least with equal force and persistency. I have said that there was a time when no atmosphere surrounded the earth; but one of the first results of the cooling of its crust must have been the formation of an atmosphere, with all the phenomena connected with it—the rising of vapors, their condensation into clouds, the falling of rains, the gathering of waters upon its surface. Water is a very active agent of destruction, but it works over again the materials it pulls down or wears away, and builds them up anew in other forms. As soon as an ocean washed over the consoli-

dated crust of the globe, it would begin to abrade the surfaces upon which it moved, gradually loosening and detaching materials, to deposit them again as sand or mud or pebbles at its bottom in successive layers, one above another. Thus, in analyzing the crust of the globe, we find at once two kinds of rocks, the respective work of fire and water: the first poured out from the furnaces within, and cooling, as one may see any mass of metal cool that is poured out from a smelting-furnace to-day, in solid crystalline masses, without any division into separate layers or leaves; and the latter in successive beds, one over another, the heavier materials below, the lighter above, or sometimes in alternate layers, as special causes may have determined successive deposits of lighter or heavier materials at some given spot.

There were many well-fought battles between geologists before it was understood that these two elements had been equally active in building up the crust of the earth. The ground was hotly contested by the disciples of the two geological schools, one of which held that the solid envelope of the earth was exclusively due to the influence of fire, while the other insisted that it had been accumulated wholly under the agency of water. This difference of opinion grew up very naturally; for the great leaders of the two schools lived in different localities, and pursued their investigations over regions where the geological phenomena were of an entirely opposite character—the one exhibiting the effect of volcanic eruptions, the other that of stratified deposits. It was the old story of the two knights on opposite sides of the shield, one swearing that it was made of gold, the other that it was made of silver, and almost killing each other before they discovered that it was made of both. So prone are men to hug their theories and shut their eyes to any antagonistic facts, that it is related of Werner, the great leader of the Aqueous school, that he was actually on his way to see a geological locality of especial interest, but, being told that it confirmed the views of his opponents, he turned round and went home again, refusing to see what might force him to change his opinions. If the rocks did not confirm his theory, so much the worse for the rocks—he would

none of them. At last it was found that the two great chemists, fire and water, had worked together in the vast laboratory of the globe, and since then scientific men have decided to work together also; and if they still have a passage at arms occasionally over some doubtful point, yet the results of their investigations are ever drawing them nearer to each other—since men who study truth, when they reach their goal, must always meet at last on common ground.

The rocks formed under the influence of heat are called, in geological language, the Igneous, or, as some naturalists have named them, the Plutonic rocks, alluding to their fiery origin, while the others have been called Aqueous or Neptunic rocks, in reference to their origin under the agency of water. A simpler term, however, quite as distinctive, and more descriptive of their structure, is that of the stratified and massive or unstratified rocks. We shall see hereafter how the relative position of these two classes of rocks and their action upon each other enable us to determine the chronology of the earth, to compare the age of her mountains, and, if we have no standard by which to estimate the positive duration of her continents, to say at least which was the first-born among them, and how their characteristic features have been successfully worked out. I am aware that many of these inferences, drawn from what is called "the geological record," must seem to be the work of the imagination. In a certain sense this is true—for imagination, chastened by correct observation, is our best guide in the study of Nature. We are too apt to associate the exercise of this faculty with works of fiction, while it is in fact the keenest detective of truth.

Besides the stratified and massive rocks, there is still a third set, produced by the contact of these two, and called, in consequence of the changes thus brought about, the Metamorphic rocks. The effect of heat upon clay is to bake it into slate; limestone under the influence of heat becomes quicklime, or, if subjected afterward to the action of water, it is changed to mortar; sand under the same agency is changed to a coarse kind of glass. Suppose, then, that a volcanic eruption takes place in a region of the earth's surface where successive layers

of limestone, of clay, and of sandstone have been previously deposited by the action of water. If such an eruption has force enough to break through these beds, the hot, melted masses will pour out through the rent, flow over its edges, and fill all the lesser cracks and fissures produced by such a disturbance. What will be the effect upon the stratified rocks? Wherever these liquid masses, melted by a heat more intense than can be produced by any artificial means, have flowed over them or cooled in immediate contact with them, the clays will be changed to slate, the limestone will have assumed a character more like marble, while the sandstone will be vitrified. This is exactly what has been found to be the case, wherever the stratified rocks have been penetrated by the melted masses from beneath. They have been themselves partially melted by the contact, and when they have cooled again, their stratification, though still perceptible, has been partly obliterated, and their substance changed. Such effects may often be traced in dikes, which are only the cracks in rocks filled by materials poured into them at some period of eruption when the melted masses within the earth were thrown out and flowed like water into any inequality or depression of the surface around. The walls enclosing such a dike are often found to be completely altered by contact with its burning contents, and to have assumed a character quite different from the rocks of which they make a part; while the mass itself which fills the fissure shows by the character of its crystallization that it has cooled more quickly on the outside, where it meets the walls, than at the center.

The first two great classes of rocks, the unstratified and stratified rocks, represent different epochs in the world's physical history: the former mark its revolutions, while the latter chronicle its periods of rest. All mountains and mountain-chains have been upheaved by great convulsions of the globe, which rent asunder the surface of the earth, destroyed the animals and plants living upon it at the time, and were then succeeded by long intervals of repose, when all things returned to their accustomed order, ocean and river deposited fresh beds in uninterrupted succession, the accumulation of materials went

on as before, a new set of animals and plants were introduced, and a time of building up and renewing followed the time of destruction. These periods of revolution are naturally more difficult to decipher than the periods of rest; for they have so torn and shattered the beds they uplifted, disturbing them from their natural relations to each other, that it is not easy to reconstruct the parts and give them coherence and completeness again. But within the last half-century this work has been accomplished in many parts of the world with an amazing degree of accuracy, considering the disconnected character of the phenomena to be studied; and I think I shall be able to convince my readers that the modern results of geological investigation are perfectly sound logical inferences from well-established facts. In this, as in so many other things, we are but "children of a larger growth." The world is the geologist's great puzzle-box; he stands before it like the child to whom the separate pieces of his puzzle remain a mystery till he detects their relation and sees where they fit, and then his fragments grow at once into a connected picture beneath his hand. . . .

When geologists first turned their attention to the physical history of the earth, they saw at once certain great features which they took to be the skeleton and basis of the whole structure. They saw the great masses of granite forming the mountains and mountain-chains, with the stratified rocks resting against their slopes; and they assumed that granite was the first primary agent, and that all stratified rocks must be of a later formation. Although this involved a partial error, as we shall see hereafter when we trace the upheavals of granite even into comparatively modern periods, yet it held an important geological truth also; for, though granite formations are by no means limited to those early periods, they are nevertheless very characteristic of them, and are indeed the foundation-stones on which the physical history of the globe is built.

Starting from this landmark, the earlier geologists divided the world's history into three periods. As the historian recognizes Ancient History, the Middle Ages, and Modern History, as distinct phases in the growth of the human race, so they distinguished between what they called the Primary period, when,

as they believed, no life stirred on the surface of the earth; the Secondary or Middle period, when animals and plants were introduced, and the land began to assume continental proportions; and the Tertiary period, or comparatively modern geological times, when the physical features of the earth as well as its inhabitants were approaching more nearly to the present condition of things. But as their investigations proceeded, they found that every one of these great ages of the world's history was divided into numerous lesser epochs, each of which had been characterized by a peculiar set of animals and plants, and had been closed by some great physical convulsion, disturbing and displacing the materials accumulated during such a period of rest.

The further study of these subordinate periods showed that what had been called Primary formations, namely, the volcanic or Plutonic rocks formerly believed to be confined to the first geological ages, belonged to all the periods, successive eruptions having taken place at all times, pouring up through the accumulated deposits penetrating and injecting their cracks, fissures, and inequalities, as well as throwing out large masses on the surface. Up to our own day there has never been a period when such eruptions have not taken place, though they have been constantly diminishing in frequency and extent. In consequence of this discovery, that rocks of igneous character were by no means exclusively characteristic of the earliest times, they are now classified together upon very different grounds from those on which geologists first united them; though, as the name *Primary* was long retained, we still find it applied to them, even in geological works of quite recent date. This defect of nomenclature is to be regretted, as likely to mislead the student, because it seems to refer to time; whereas it no longer signifies the age of the rocks, but simply their character. The name Plutonic or Massive rocks is, however, now almost universally substituted for that of Primary.

A wide field of investigation still remains to be explored by the chemist and the geologist together, in the mineralogical character of the Plutonic rocks, which differs greatly in the different periods. The earlier eruptions seem to have been

chiefly granitic, though this must not be understood in too wide a sense since there are granite formations even as late as the Tertiary period; those of the middle periods were mostly porphyries and basalts; while in the more recent ones lavas predominate. We have as yet no clew to the laws by which this distribution of volcanic elements in the formation of the earth is regulated; but there is found to be a difference in the crystals of the Plutonic rocks belonging to different ages, which, when fully understood, may enable us to determine the age of any Plutonic rock by its mode of crystallization; so that the mineralogist will as readily tell you by its crystals whether a bit of stone of igneous origin belongs to this or that period of the world's history, as the palæontologist will tell you by its fossils whether a piece of rock of aqueous origin belongs to the Silurian or Devonian or Carboniferous deposits.

GEOLOGY

Composition and Material of the Earth's Crust

By AGNES GIBERNE

WHAT is the earth made of—this round earth upon which we human beings live and move?

A question more easily asked than answered, as regards a very large portion of it. For the earth is a huge ball nearly eight thousand miles in diameter, and we who dwell on the outside have no means of getting down more than a very little way below the surface. So it is quite impossible for us to speak positively as to the inside of the earth, and what it is made of. Some people believe the earth's inside to be hard and solid, while others believe it to be one enormous lake or furnace of fiery melted rock. But nobody really knows.

This outside crust has been reckoned to be of many different thicknesses. One man will say it is ten miles thick, and another will rate it at four hundred miles. So far as regards man's knowledge of it, gained from mining, from boring, from examination of rocks, and from reasoning out all that may be learned from these observations, we shall allow an ample margin if we count the field of geology to extend some twenty miles downwards from the highest mountain-tops. Beyond this we find ourselves in a land of darkness and conjecture.

Twenty miles is only one four-hundredth part of the earth's diameter—a mere thin shell over a massive globe. If the earth were brought down in size to an ordinary large school globe, a piece of rough brown paper covering it might well represent

the thickness of this earth-crust, with which the science of geology has to do. And the whole of the globe, this earth of ours, is but one tiny planet in the great Solar System. And the center of that Solar System, the blazing sun, though equal in size to more than a million earths, is yet himself but one star amid millions of twinkling stars, scattered broadcast through the universe. So it would seem at first sight that the field of geology is a small field compared with that of astronomy. . . .

With regard to the great bulk of the globe little can be said. Very probably it is formed through and through of the same materials as the crust. This we do not know. Neither can we tell, even if it be so formed, whether the said materials are solid and cold like the outside crust, or whether they are liquid with heat. The belief has been long and widely held that the whole inside of the earth is one vast lake or furnace of melted fiery-hot material, with only a thin cooled crust covering it. Some in the present day are inclined to question this, and hold rather that the earth is solid and cold throughout, though with large lakes of liquid fire here and there, under or in the crust, from which our volcanoes are fed. . . .

The materials of which the crust is made are many and various; yet, generally speaking, they may all be classed under one simple word, and that word is—*Rock*.

It must be understood that, when we talk of rock in this geological sense, we do not only mean hard and solid stone, as in common conversation. Rock may be changed by heat into a liquid or "molten" state, as ice is changed by heat to water. Liquid rock may be changed by yet greater heat to vapor, as water is changed to steam, only we have in a common way no such heat at command as would be needed to effect this. Rock may be hard or soft. Rock may be chalky, clayey, or sandy. Rock may be so close-grained that strong force is needed to break it; or it may be so porous—so full of tiny holes—that water will drain through it; or it may be crushed and crumbled into loose grains, among which you can pass your fingers.

The cliffs above our beaches are rock; the sand upon our seashore is rock; the clay used in brick-making is rock; the

limestone of the quarry is rock; the marble of which our mantel-pieces are made is rock. The soft sandstone of South Devon, and the hard granite of the north of Scotland, are alike rock. The pebbles in the road are rock; the very mold in our gardens is largely composed of crumbled rock. So the word in its geological sense is a word of wide meaning.

Now the business of the geologist is to read the history of the past in these rocks of which the earth's crust is made.

Rocks may be divided into several kinds or classes. For the present moment it will be enough to consider the two grand divisions—*Stratified Rocks and Unstratified Rocks*.

Unstratified rocks are those which were once, at a time more or less distant, in a melted state from intense heat, and which have since cooled into a half *crystallized* state; much the same as water, when growing colder, cools and crystallizes into ice. Strictly speaking ice is rock, just as much as granite and sandstone are rock. Water itself is of the nature of rock, only as we commonly know it in the liquid state we do not commonly call it so.

"Crystallization" means those particular forms or shapes in which the particles of a liquid arrange themselves, as that liquid hardens into a solid—in other words, as it freezes. Granite, iron, marble, are frozen substances, just as truly as ice is a frozen substance; for with greater heat they would all become liquid like water. When a liquid freezes, there are always crystals formed, though these are not always visible without the help of a microscope. Also the crystals are of different shapes with different substances.

If you examine the surface of a puddle or pond, when a thin covering of ice is beginning to form, you will be able to see plainly the delicate, sharp, needle-like forms of the ice crystals. Break a piece of ice, and you will find that it will not easily break just in any way that you may choose, but it will only split along the lines of these needle-like crystals. This particular mode of splitting in a crystallized rock is called the *cleavage* of that rock.

Crystallization may take place either slowly or rapidly, and either in the open air or far below ground. The lava from a

volcano is an example of rock which has crystallized rapidly in the open air; and granite is an example of rock which has crystallized slowly underground beneath great pressure.

Stratified rocks, on the contrary, which make up a very large part of the earth's crust, are not crystallized. Instead of having cooled from a liquid into a solid state, they have been slowly *built up*, bit by bit and grain upon grain, into their present form, through long ages of the world's history. The materials of which they are made were probably once, long, long ago, the crumbings from granite and other crystallized rocks, but they show now no signs of crystallization.

They are called "stratified" because they are in themselves made up of distinct layers, and also because they lie thus one upon another in layers, or *strata*, just as the leaves of a book lie, or as the bricks of a house are placed.

Throughout the greater part of Europe, of Asia, of Africa, of North and South America, of Australia, these rocks are to be found, stretching over hundreds of miles together, north, south, east, and west, extending up to the tops of some of the earth's highest mountains, reaching down deep into the earth's crust. In many parts if you could dig straight downward through the earth for thousands of feet, you would come to layer after layer of these stratified rocks, one kind below another, some layers thick, some layers thin, here a stratum of gravel, there a stratum of sandstone, here a stratum of coal, there a stratum of clay.

But how, when, where, did the building up of all these rock-layers take place?

People are rather apt to think of land and water on the earth as if they were fixed in one changeless form—as if every continent and every island were of exactly the same shape and size now that it always has been and always will be.

Yet nothing can be further from the truth. The earth-crust is a scene of perpetual change, of perpetual struggle, of perpetual building up, of perpetual wearing away.

The work may go on slowly, but it does go on. The sea is always fighting against the land, beating down her cliffs, eating into her shores, swallowing bit by bit of solid earth; and rain

and frost and inland streams are always busily at work, helping the ocean in her work of destruction. Year by year and century by century it continues. Not a country in the world which is bordered by the open sea has precisely the same coastline that it had one hundred years ago; not a land in the world but parts each century with masses of its material, washed piecemeal away into the ocean.

See the effect upon the beach of one night's fierce storm. Mark the pathway on the cliff, how it seems to have crept so near the edge that here and there it is scarcely safe to tread; and very soon, as we know, it will become impassable. Just from a mere accident, of course—the breaking away of some of the earth, loosened by rain and frost and wind. But this is an accident which happens daily in hundreds of places around the shores.

Leaving the ocean, look now at this river in our neighborhood, and see the slight muddiness which seems to color its waters. What from? Only a little earth and sand carried off from the banks as it flowed—very unimportant and small in quantity, doubtless, just at this moment and just at this spot. But what of that little going on week after week, and century after century, throughout the whole course of the river, and throughout the whole course of every river and rivulet in our whole country and in every other country? A vast amount of material must every year be thus torn from the land and given to the ocean. For the land's loss here is the ocean's gain.

And, strange to say, we shall find that this same ocean, so busily engaged with the help of its tributary rivers in pulling down land, is no less busily engaged with their help in building it up.

You have sometimes seen directions upon a vial of medicine to "shake" before taking the dose. When you have so shaken the bottle the clear liquid grows thick; and if you let it stand for a while the thickness goes off, and a fine grain-like or dust-like substance settles down at the bottom—the settlement or *sediment* of the medicine. The finer this sediment, the slower it is in settling. If you were to keep the liquid in gentle motion the fine sediment would not settle down at the bottom.

With coarser and heavier grains the motion would have to be quicker to keep them supported in the water.

Now it is just the same thing with our rivers and streams. Running water can support and carry along sand and earth, which in still water would quickly sink to the bottom; and the more rapid the movement of the water, the greater is the weight it is able to bear.

This is plainly to be seen in the case of a mountain torrent. As it foams fiercely through its rocky bed it bears along, not only mud and sand and gravel, but stones and even small rocks, grinding the latter roughly together till they are gradually worn away, first to rounded pebbles, then to sand, and finally to mud. The material thus swept away by a stream, ground fine, and carried out to sea—part being dropped by the way on the river-bed—is called *detritus*, which simply means *worn-out* material.

The tremendous carrying-power of a mountain torrent can scarcely be realized by those who have not observed it for themselves. I have seen a little mountain-stream swell in the course of a heavy thunder-storm to such a torrent, brown and turbid with earth torn from the mountain-side, and sweeping resistlessly along in its career a shower of stones and rock-fragments. That which happens thus occasionally with many streams is more or less the work all the year round of many more.

As the torrent grows less rapid, lower down in its course, it ceases to carry rocks and stones, though the grinding and wearing away of stones upon the rocky bed continue, and coarse gravel is borne still upon its waters. Presently the widening stream, flowing yet more calmly, drops upon its bed all such coarser gravel as is not worn away to fine earth, but still bears on the lighter grains of sand. Next the slackening speed makes even the sand too heavy a weight, and that in turn falls to line the river-bed, while the now broad and placid stream carries only the finer particles of mud suspended in its waters. Soon it reaches the ocean, and the flow being there checked by the incoming ocean-tide, even the mud can no longer be held up, and it also sinks slowly in the shallows near the shore, forming sometimes broad mud-banks dangerous to the mariner.

This is the case only with smaller rivers. Where the stream is stronger, the mud-banks are often formed much farther out at sea; and more often still the river-detritus is carried away and shed over the ocean-bed, beyond the reach of our ken. The powerful rush of water in earth's greater streams bears enormous masses of sand and mud each year far out into the ocean, there dropping quietly the gravel, sand, and earth, layer upon layer at the bottom of the sea. Thus pulling down and building up go on ever side by side; and while land is the theater oftentimes of decay and loss, ocean is the theater oftentimes of renewal and gain.

Did you notice the word "sediment" used a few pages back about the settlement at the bottom of a medicine-vial?

There is a second name given to the stratified rocks, of which the earth's crust is so largely made up. They are called also *Sedimentary Rocks*.

The reason is simply this. The stratified rocks of the present day were once upon a time made up out of the sediment stolen first from land and then allowed to settle down on the sea-bottom.

Long, long ago, the rivers, the streams, the ocean, were at work, as they are now, carrying away rock and gravel, sand and earth. Then, as now, all this material, borne upon the rivers, washed to and fro by the ocean, settled down at the mouths of rivers or at the bottom of the sea, into a sediment, one layer forming up over another, gradually built up through long ages. At first it was only a soft, loose, sandy or muddy sediment, such as you may see on the seashore, or in a mud-bank. But as the thickness of the sediment increased, the weight of the layers above gradually pressed the lower layers into firm hard rocks; and still, as the work of building went on, these layers were, in their turn, made solid by the increasing weight over them. Certain chemical changes had also a share in the transformation from soft mud to hard rock, which need not be here considered.

All this has through thousands of years been going on. The land is perpetually crumbling away and fresh land under

the sea is being perpetually built up, from the very same materials which the sea and the rivers have so mercilessly stolen from continents and islands. This is the way, if geologists rightly judge, in which a very large part of the enormous formations of stratified or sedimentary rocks have been made.

So far is clear. But now we come to a difficulty.

The stratified rocks, of which a very large part of the continents is made, appear to have been built up slowly, layer upon layer, out of the gravel, sand, and mud, washed away from the land and dropped on the shore of the ocean.

You may see these layers for yourself as you walk out into the country. Look at the first piece of bluff rock you come near, and observe the clear pencil-like markings of layer above layer—not often indeed lying *flat*, one over another, and this must be explained later, but, however irregularly slanting, still plainly visible. You can examine these lines of stratification on the nearest cliff, the nearest quarry, the nearest bare head-land, in your neighborhood.

But how can this be? If all these stratified rocks are built on the floor of the ocean out of material taken *from* the land, how can we by any possibility find such rocks *upon* the land? In the beds of rivers we might indeed expect to see them, but surely nowhere else save under ocean waters.

Yet find them we do. Through the two great world-continents, they abound on every side. Thousands of miles in unbroken succession are composed of such rocks.

Stand with me near the seashore, and let us look around. See, in the rough sides of yonder bluff the markings spoken of, fine lines running alongside of one another, sometimes flat, sometimes bent or slanting, but always giving the impression of layer piled upon layer. Yet how can one for a moment suppose that the ocean-waters ever rose so high? Look again at yonder cliff, and observe a little way below the top a singular band of shingles, squeezed into the cliff, as it were, with chalk below and earth above.

That is believed to be an old sea-beach. Once upon a time the waters of the sea are supposed to have washed those shin-

gles, as now they wash the shore near which we stand, and all the white cliff must have lain then beneath the ocean.

Geologists were for a long while sorely puzzled to account for these old sea-beaches, found high up in the cliffs around our land in many different places.

They had at first a theory that the sea must once, in far back ages, have been a great deal higher than it is now. But this explanation only brought about fresh difficulties. It is quite impossible that the level of the sea should be higher in one part of the world than in another. Besides, in some places remains of sea-animals are found in mountain heights, as much as two or three thousand feet above the sea-level—as, for instance, in Corsica. This very much increases the difficulty of the above explanation.

So another theory was started instead, and this is now generally supposed to be the true one. What if, instead of the whole ocean having been higher, parts of the land were lower? England at one time, parts of Europe at another time, parts of Asia and America at other times, may have slowly sunk beneath the ocean, and after long remaining there have slowly risen again.

This is by no means so wild a supposition as it may seem when first heard, and as it doubtless did seem when first proposed. For even in the present day these movements of the solid crust of our earth are going on. The coasts of Sweden and Finland have long been slowly and steadily rising out of the sea, so that the waves can no longer reach so high upon those shores as in years gone by they used to reach. In Greenland, on the contrary, land has long been slowly and steadily sinking, so that what used to be the shore now lies under the sea. Other such risings and sinkings might be mentioned, as also many more in connection with volcanoes and earthquakes, which are neither slow nor steady, but sudden and violent.

So it becomes no impossible matter to believe that, in the course of ages past, all those wide reaches of our continents and islands, where sedimentary rocks are to be found, were each in turn, at one time or another, during long periods, beneath the rolling waters of the ocean. . . .

These built-up rocks are not only called "Stratified," and "Sedimentary." They have also the name of *Aqueous Rock*, from the Latin word *aqua*, *water*; because they are believed to have been formed by the action of the water.

They have yet another and fourth title, which is *Fossiliferous Rocks*.

Fossils are the hardened remains of animals and vegetables found in rocks. They are rarely, if ever, seen in unstratified rocks; but many layers of stratified rocks abound in these remains. Whole skeletons as well as single bones, whole tree-trunks as well as single leaves, are found thus embedded in rock layers, where in ages past the animal or plant died and found a grave. They exist by thousands in many parts of the world, varying in size from the huge skeleton of the elephant to the tiny shell of the microscopic animalcule.

Fossils differ greatly in kind. Sometimes the entire shell or bone is changed into stone, losing all its animal substance, but retaining its old outline and its natural markings. Sometimes the fossil is merely the hardened impress of the outside of a shell or leaf, which has dented its picture on soft clay, and has itself disappeared, while the soft clay has become rock, and the indented picture remains fixed through after-centuries. Sometimes the fossil is the cast of the inside of a shell; the said shell having been filled with soft mud, which has taken its exact shape and hardened, while the shell itself has vanished. The most complete description of fossil is the first of these three kinds. It is wonderfully shown sometimes in fossil wood, where all the tiny cells and delicate fibers remain distinctly marked as of old, only the whole woody substance has changed into hard stone.

But although the fossil remains of quadrupeds and other land-animals are found in large quantities, their number is small compared with the enormous number of fossil sea-shells and sea-animals.

Land-animals, as a rule, have been so preserved only when they have been drowned in ponds or rivers, or mired in bogs and swamps, or overtaken by frost or swept out to sea.

Sea-animals, on the contrary, have been so preserved on

land whenever that land has been under the sea; and this appears to have been the case, at one or another past age, with the greater part of our present continents. These fossil remains of sea animals are discovered in all quarters of the world, not only on the seashore but also far inland, not only deep down underground but also high up on the tops of lofty mountains—a plain proof that over the summits of those mountains the ocean must once have rolled, and this not for a brief space only, but through long periods of time. And not on the mountain-summit only are these fossils known to abound, but sometimes in layer below layer of the mountain, from top to bottom, through thousands of feet of rock.

This may well seem puzzling at first sight. Fossils of sea-creatures on a mountain-top are startling enough; yet hardly so startling as the thought of fossils *inside* that mountain. How could they have found their way thither?

The difficulty soon vanishes, if once we clearly understand that all these thousands of feet of rock were built up slowly, layer after layer, when portions of the land lay deep under the sea. Thus *each separate layer* of mud or sand or other material became in its turn the *top layer*, and was for the time the floor of the ocean, until further droppings of material out of the waters made a fresh layer, covering up the one below.

While each layer was thus in succession the top layer of the building, and at the same time the floor of the ocean, animals lived and died in the ocean, and their remains sank to the bottom, resting upon the sediment floor. Thousands of such dead remains disappeared, crumbling into fine dust and mingling with the waters, but here and there one was caught captive by the half-liquid mud, and was quickly covered and preserved from decay. And still the building went on, and still layer after layer was placed, till many fossils lay deep down beneath the later-formed layers; and when at length, by slow or quick upheaval of the ground, this sea-bottom became a mountain, the little fossils were buried within the body of that mountain. So wondrously the matter appears to have come about.

Another difficulty with respect to the stratified rocks has to be thought of. All these layers or deposits of gravel, sand, or

earth, on the floor of the ocean, would naturally be horizontal—that is, would lie flat, one upon another. In places the ocean-floor might slant, or a crevice or valley or ridge might break the smoothness of the deposit. But though the layers might partake of the slant, though the valley might have to be filled, though the ridge might have to be surmounted, still the general tendency of the waves would be to level the dropping deposits into flat layers.

Then how is it that when we examine the strata of rocks in our neighborhood, wherever that neighborhood may be, we do not find them so arranged? Here, it is true, the lines for a space are nearly horizontal, but there, a little way farther on, they are perpendicular; here they are bent, and there curved; here they are slanting, and there crushed and broken.

This only bears out what has been already said about the Book of Geology. It *has* been bent and disturbed, crushed and broken.

Great powers have been at work in this crust of our earth. Continents have been raised, mountains have been upheaved, vast masses of rock have been scattered into fragments. Here or there we may find the layers arranged as they were first laid down, but far more often we discover signs of later disturbance, either slow or sudden, varying from a mere quiet tilting to a violent overturn.

So the Book of Geology is a torn and disorganized volume, not easy to read.

Yet, on the other hand, these very changes which have taken place are a help to the geologist.

It may seem at first sight as if we should have an easier task, if the strata were all left lying just as they were first formed, in smooth level layers, one above another. But if it were so, we could know very little about the lower layers.

We might indeed feel sure, as we do now, that the lowest layers were the oldest and the top layers the newest, and that any fossils found in the lower layers must belong to an age farther back than any fossils found in the upper layers.

So much would be clear. And we might dig also and burrow a little way down, through a few different kinds of rock,

where they were not too thick. But that would be all. There our powers would cease.

Now how different. Through the heavings and tiltings of the earth's crust, the lower layers are often pushed quite up to the surface, so that we are able to examine them and their fossils without the least difficulty, and very often without digging underground at all.

You must not suppose that the real order of the rocks is changed by these movements, for generally speaking it is not. The lower kinds are rarely, if ever, found placed *over* the upper kinds; only the ends of them are seen peeping out above ground.

It is as if you had a pile of copy-books lying flat one upon another, and were to put your finger under the lowest and push it up. All those above would be pushed up also, and perhaps they would slip a little way down, so that you would have a row of *edges* showing side by side, at very much the same height. The arrangement of the copy-books would not be changed, for the lowest would still be the lowest in actual position; but a general tilting or upheaval would have taken place.

Just such a tilting or upheaval has taken place again and again with the rocks forming our earth-crust. The edges of the lower rocks often show side by side with those of higher layers.

But geologists know them apart. They are able to tell confidently whether such and such a rock, peeping out at the earth's surface, belongs really to a lower or a higher kind. For there is a certain sort of order followed in the arrangement of rock-layers all over the earth, and it is well known that some rocks are never found below some other rocks, that certain particular kinds are never placed above certain other kinds. Thus it follows that the fossils found in one description of rock must be the fossils of animals which lived and died before the animals whose fossil remains are found in another neighboring rock, just because this last rock-layer was built upon the ocean-floor above and therefore later than the other.

All this is part of the foreign language of geology—part of the piecing and arranging of the torn volume. Many mistakes

are made; many blunders are possible; but the mistakes and blunders are being gradually corrected, and certain rules by which to read and understand are becoming more and more clear.

It has been already said that unstratified rocks are those which have been at some period, whether lately or very long ago, in a liquid state from intense heat, and which have since cooled, either quickly or slowly, crystallizing as they cooled.

Unstratified rocks may be divided into two distinct classes.

First.—Volcanic rocks, such as lava. These have been quickly cooled at the surface of the earth, or not far below it.

Secondly.—Plutonic rocks, such as granite. These have been slowly cooled deep down in the earth under heavy pressure.

There is also a class of rocks, called metamorphic rocks, including some kinds of marble. These are, strictly speaking, crystalline rocks, and yet they are arranged in something like layers. The word “metamorphic” simply means “transformed.” They are believed to have been once stratified rocks, perhaps containing often the remains of animals; but intense heat has later transformed them into crystalline rocks, and the animal remains have almost or quite vanished.

Just as the different kinds of stratified rocks are often called aqueous rocks, or rocks formed by the action of water—so these different kinds of unstratified rocks are often called igneous rocks, or rocks formed by the action of fire—the name being taken from the Latin word for fire. The metamorphic rocks are sometimes described as “Aqueo-igneous,” since both water and fire helped in the forming of them.

It was at one time believed, as a matter of certainty, that granite and such rocks belonged to a period much farther back than the periods of the stratified rocks. That is to say, it was supposed that fire-action had come first and water-action second; that the fire-made rocks were all formed in very early ages, and that only water-made rocks still continued to be formed. So the name of Primary Rocks, or First Rocks, was given to the granites and other such rocks, and the name of Secondary Rocks to all water-built rocks, while those of the third class were called Transition Rocks, because they seemed

to be a kind of link or stepping-stone in the change from the First to the Second Rocks.

The chief reason for the general belief that fire-built rocks were older than water-built ones was, that the former are as a rule found to lie *lower* than the latter. They form, as it were, the basement of the building, while the top-stories are made of water-built rocks.

Many still believe that there is much truth in the thought. It is most probable, so far as we are able to judge, that the *first formed* crust of rocks all over the earth was of cooled and crystallized material. As these rocks were crumbled and wasted by the ocean, materials would have been supplied for the building-up of rocks, layer upon layer.

But this is conjecture. We cannot know with any certainty the course of events so far back in the past. And geologists are now able to state with tolerable confidence that, however old many of the granites may be, yet a large amount of the fire-built rocks are no older than the water-built rocks which lie over them.

So by many geologists the names of Primary, Transition, and Secondary Formations are pretty well given up. It has been proposed to give instead to the crystallized rocks of all kinds the name of Underlying Rocks (Hypogene Rocks).

But if they really do lie under, how can they possibly be of the same age? One would scarcely venture to suppose, in looking at a building, that the cellars had not been finished before the upper floors.

True. In the first instance doubtless the cellars were first made, then the ground-floor, then the upper stories.

When, however, the house was so built, alterations and improvements might be very widely carried on above and below. While one set of workmen were engaged in remodeling the roof, another set of workmen might be engaged in remodeling the kitchens and first floor, pulling down, propping up, and actually rebuilding parts of the lower walls.

This is precisely what the two great fellow-workmen, Fire and Water, are ever doing in the crust of our earth. And if it be objected that such alterations too widely undertaken might

result in slips, cracks, and slidings, of ceilings and walls in the upper stories, I can only say that such catastrophes *have* been the result of underground alterations in that great building, the earth's crust. . . .

We see therefore clearly that, although the earliest fire-made rocks may very likely date farther back than the earliest water-made rocks, yet the making of the two kinds has gone on side by side, one below and the other above ground, through all ages up to the present moment.

And just as in the present day water continues its busy work above ground of pulling down and building up, so also fire continues its busy work underground of melting rocks which afterward cool into new forms, and also of shattering and upheaving parts of the earth-crust.

For there can be no doubt that fiery heat does exist as a mighty power within our earth, though to what extent we are not able to say.

These two fellow-workers in nature have different modes of working. One we can see on all sides, quietly progressing, demolishing land patiently bit by bit, building up land steadily grain by grain. The other, though more commonly hidden from sight, is fierce and tumultuous in character, and shows his power in occasional terrific outbursts.

We can scarcely realize what the power is of the imprisoned fiery forces underground, though even we are not without some witness of their existence. From time to time even our firm land has been felt to tremble with a thrill from some far-off shock; and even in our country is seen the marvel of scalding water pouring unceasingly from deep underground

Think of the tremendous eruptions of Vesuvius, of Etna, of Hecla, of Mauna Loa. Think of whole towns crushed and buried, with their thousands of living inhabitants. Think of rivers of glowing lava streaming up from regions below ground, and pouring along the surface for a distance of forty, fifty, and even sixty miles, as in Iceland and Hawaii. Think of red-hot cinders flung from a volcano-crater to a height of 10,000 feet. Think of lakes of liquid fire in other craters, five hundred to a

thousand feet across, huge caldrons of boiling rock. Think of showers of ashes from the furnace below of yet another, borne so high aloft as to be carried seven hundred miles before they sank to earth again. Think of millions of red-hot stones flung out in one eruption of Vesuvius. Think of a mass of rock, one hundred cubic yards in size, hurled to a distance of eight miles or more out of the crater of Cotopaxi.

Think also of earthquake-shocks felt through 1,200 miles of country. Think of fierce tremblings and heavings lasting in constant succession through days and weeks of terror. Think of hundreds of miles of land raised several feet in one great upheaval. Think of the earth opening in scores of wide-lipped cracks, to swallow men and beasts. Think of hot mud, boiling water, scalding steam, liquid rock, bursting from such cracks, or pouring from rents in a mountain-side.

Truly these are signs of a state of things in or below the solid crust on which we live, that may make us doubt the absolute security of "Mother Earth."

Different explanations have been put forward to explain this seemingly fiery state of things underground.

Until lately the belief was widely held that our earth was one huge globe of liquid fire, with only a slender cooled crust covering her, a few miles in thickness.

This view was supported by the fact that heat is found to increase as men descend into the earth. Measurements of such heat-increase have been taken, both in mines and in borings for wells. The usual rate is about one degree more of heat, of our common thermometer, for every fifty or sixty feet of descent. If this were steadily continued, water would boil at a depth of 8,000 feet below the surface; iron would melt at a depth of twenty-eight miles; while at a depth of forty or fifty miles no known substance upon earth could remain solid.

The force of this proof is, however, weakened by the fact that the rate at which the heat increases differs very much in different places. Also it is now generally supposed that such a tremendous furnace of heat—a furnace nearly 8,000 miles in

diameter—could not fail to break up and melt so slight a covering shell.

Many believe, therefore, not that the whole interior of the earth is liquid with heat, but that enormous fire-seas or lakes of melted rock exist here and there, under or in the earth-crust. From these lakes the volcanoes would be fed, and they would be the cause of earthquakes and land-upheavals or land-sinking. There are strong reasons for supposing that the earth was once a fiery liquid body, and that she has slowly cooled through long ages. Some hold that her center probably grew solid first from tremendous pressure; that her crust afterward became gradually cold; and that between the solid crust and the solid inside or “nucleus,” a sea of melted rock long existed, the remains of which are still to be found in these tremendous fiery reservoirs.

The idea accords well with the fact that large numbers of extinct or dead volcanoes are scattered through many parts of the earth. If the above explanation be the right one, doubtless the fire-seas in the crust extended once upon a time beneath such volcanoes, but have since died out or smoldered low in those parts.

A somewhat curious calculation has been made, to illustrate the different modes of working of these two mighty powers—Fire and Water.

The amount of land swept away each year in mud, and borne to the ocean by the River Ganges, was roughly reckoned, and also the amount of land believed to have been upheaved several feet in the great Chilian earthquake.

It was found that the river, steadily working month by month, would require some four hundred years to carry to the sea the same weight of material, which in one tremendous effort was upheaved by the fiery underground forces.

Yet we must not carry this distinction too far. Fire does not always work suddenly, or water slowly; witness the slow rising and sinking of land in parts of the earth, continuing through centuries; and witness also the effects of great floods and storms.

The crust of the earth is made of rock. But what is rock made of?

Certain leading divisions of rocks have been already considered:

The Water-made Rocks;

The Fire-made Rocks, both Plutonic and Volcanic;

The Water-and-Fire-made Rocks.

The first of these—Water-made Rocks—may be subdivided into three classes. These are,—

I. *Flint Rocks*;

II. *Clay Rocks*;

III. *Lime Rocks*.

This is not a book in which it would be wise to go closely into the mineral nature of rocks. Two or three leading thoughts may, however, be given.

Does it not seem strange that the hard and solid rocks should be in great measure formed of the same substances which form the thin invisible air floating around us?

Yet so it is. There is a certain gas called oxygen gas. Without that gas you could not live many minutes. Banish it from the room in which you are sitting, and in a few minutes you will die.

This gas makes up nearly one-quarter by weight of the atmosphere round the whole earth.

The same gas plays an important part in the ocean; for more than three-quarters of water is *oxygen*.

It plays also an important part in rocks; for about half the material of the entire earth's crust is *oxygen*.

Another chief material in rocks is *silicon*. This makes up one-quarter of the crust, leaving only one-quarter to be accounted for. Silicon mixed with oxygen makes silica or quartz. There are few rocks which have not a large amount of quartz in them. Common flint, sandstones, and the sand of our shores are made of quartz, and therefore belong to the first class of silicious or flint rocks. Granites and lavas are about one-half quartz. The beautiful stones, amethyst, agate, chalcedony, and jasper, are all different kinds of quartz.

Another chief material in rocks is a white metal called *aluminium*. United to oxygen it becomes alumina, the chief substance in clay. Rocks of this kind—such as clays, and also

the lovely blue gem, sapphire—are called argillaceous rocks, from the Latin word for clay, and belong to the second class. Such rocks keep fossils well.

Another is *calcium*. United to oxygen and carbonic acid, it makes carbonate of lime, the chief substance in limestone; so all limestones belong to the third class of calcareous or lime rocks.

Other important materials may be mentioned, such as *magnesium, potassium, sodium, iron, carbon, sulphur, hydrogen, chlorine, nitrogen*. These, with many more, not so common, make up the remaining quarter of the earth-crust.

Carbon plays as important a part in animal and vegetable life as silicon in rocks. Carbon is most commonly seen in three distinct forms—as charcoal, as black-lead, and as the pure brilliant diamond. Carbon united, in a particular proportion, to oxygen, forms carbonic acid; and carbonic acid united, in a particular proportion, to lime, forms limestone.

Hydrogen united to oxygen forms water. Each of these two gases is invisible alone, but when they meet and mingle they form a liquid.

Nitrogen united to oxygen and to a small quantity of carbonic acid gas forms our atmosphere.

Rocks of pure flint, pure clay, or pure lime are rarely or never met with. Most rocks are made up of several different substances melted together.

In the fire-built rocks no remains of animals are found, though in water-built rocks they abound. Water-built rocks are sometimes divided into two classes—those which only contain occasional animal remains, and those which are more or less built up of the skeletons of animals.

There are some exceedingly tiny creatures inhabiting the ocean, called Rhizopods. They live in minute shells, the largest of which may be almost the size of a grain of wheat, but by far the greater number are invisible as shells without a microscope, and merely show as fine dust. The rhizopods are of different shapes, sometimes round, sometimes spiral, sometimes having only one cell, sometimes having several cells. In

the latter case a separate animal lives in each cell. The animal is of the very simplest as well as the smallest kind. He has not even a mouth or a stomach, but can take in food at any part of his body.

These rhizopods live in the oceans in enormous numbers. Tens of millions are ever coming into existence, living out their tiny lives, dying, and sinking to the bottom. There upon the ocean-floor gather their remains, a heaped-up multitude of minute skeletons or shells, layer forming over layer.

It was long suspected that the white chalk cliffs of England were built up in some such manner as this through past ages. And now at length proof has been found, in the shape of mud dredged up from the ocean-bottom—mud entirely composed of countless multitudes of these little shells, dropping there by myriads, and becoming slowly joined together in one mass.

Just so, it is believed, were the white chalk cliffs built—gradually prepared on the ocean-floor, and then slowly or suddenly upheaved, so as to become a part of the dry land.

Think what the enormous numbers must have been of tiny living creatures, out of whose shells the wide reaches of white chalk cliffs have been made. Chalk cliffs and chalk layers extend from Ireland, through England and France, as far as to the Crimea. In the south of Russia they are said to be six hundred feet thick. Yet one cubic inch of chalk is calculated to hold the remains of more than one million rhizopods. How many countless millions upon millions must have gone to the whole structure! How long must the work of building up have lasted!

These little shells do not always drop softly and evenly to the ocean-floor, to become quietly part of a mass of shells. Sometimes, where the ocean is shallow enough for the waves to have power below, or where land currents can reach, they are washed about, and thrown one against another, and ground into fine powder; and the fine powder becomes in time, through different causes, solid rock.

Limestone is made in another way also. In the warm waters of the South Pacific Ocean there are many islands,

large and small, which have been formed in a wonderful manner by tiny living workers. The workers are soft jelly-like creatures, called polyps, who labor together in building up great walls and masses of coral.

They never carry on their work above the surface of the water, for in the air they would die. But the waves break the coral, and heap it up above high-water mark, and carry earth and seeds to drop there till at length a small low-lying island is formed.

The waves not only heap up broken coral, but they grind the coral into fine powder, and from this powder limestone rock is made, just as it is from the powdered shells of rhizopods. The material used by the polyps in building the coral is chiefly lime, which they have the power of gathering out of the water, and the fine coral-powder, sinking to the bottom, makes large quantities of hard limestone. Soft chalk is rarely, if ever, found near the coral islands.

Limestones are formed in the same manner from the grinding up of other sea-shells and fossils, various in kind; the powder becoming gradually united into solid rock.

There is yet another way in which limestone is made, quite different from all these. Sometimes streams of water have a large quantity of lime in them; and these as they flow will drop layers of lime which harden into rock. Or a lime-laden spring, making its way through the roof of an underground cavern, will leave all kinds of fantastic arrangements of limestone wherever its waters can trickle and drip. Such a cavern is called a "stalactite cave."

So there are different kinds of fossil rock-making. There may be rocks made of other materials, with fossil simply buried in them. There may be rocks made entirely of fossils, which have gathered in masses as they sank to the sea-bottom, and have there become simply and lightly joined together. There may be rocks made of the ground-up powder of fossils, pressed into a solid substance or united by some other substance.

Rocks are also-often formed of whole fossils, or stones, or shells, bound into one by some natural soft sticky cement,

which has gathered round them and afterward grown hard, like the cement which holds together the stones in a wall.

The tiny rhizopods (meaning root foot), which have so large a share in chalk and limestone making, are among the smallest and simplest known kinds of animal life.

There are also some very minute forms of vegetable life, which exist in equally vast numbers, called diatoms. For a long while they were believed to be living animals, like the rhizopods. Scientific men are now, however, pretty well agreed that they really are only vegetables or plants.

The diatoms have each one a tiny shell or shield, not made of lime like the rhizopod-shells, but of flint. Some think that common flint may be formed of these tiny shells.

Again, there is a kind of rock called mountain meal, which is entirely made up of the remains of diatoms. Examined under the microscope, thousands of minute flint shields of various shapes are seen. This rock, or earth, is very abundant in many places, and is sometimes used as a polishing powder. In Bohemia there is a layer of it no less than fourteen feet thick. Yet so minute are the shells of which it is composed, that one square inch of rock is said to contain about four thousand millions of them. Each one of these millions is a separate distinct fossil

If you examine carefully a piece of coal, you will find, more or less clearly, markings like those which are seen in a piece of wood. Sometimes they are very distinct indeed. Coal abounds in impressions of leaves, ferns, and stems, and fossil remains of plants and tree-trunks are found in numbers in coal-seams.

Coal is a vegetable substance. The wide coal-fields of Britain and other lands are the *fossil* remains of vast forests.

Long ages ago, as it seems, broad and luxuriant forests flourished over the earth. In many parts generation after generation of trees lived and died and decayed, leaving no trace of their existence, beyond a little layer of black mold, soon to be carried away by wind and water. Coal could only be formed where there were bogs and quagmires.

But in bogs and quagmires, and in shallow lakes of low-

lying lands, there were great gatherings of slowly decaying vegetable remains, trees, plants, and ferns all mingling together. Then after a while the low lands would sink and the ocean pouring in would cover them with layers of protecting sand or mud; and sometimes the land would rise again, and fresh forests would spring into life, only to be in their turn overwhelmed anew, and covered by fresh sandy or earthy deposits.

These buried forests lay through the ages following, slowly hardening into the black and shining coal, so useful now to man.

The coal is found thus in thin or thick seams, with other rock-layers between, telling each its history of centuries long past. In one place no less than sixteen such beds of coal are found, one below another, each divided from the next above and the next underneath by beds of clay or sand or shale. The forests could not have grown in the sea, and the earth-layers could not have been formed on land, therefore many land-risings and sinkings must have taken place. Each bed probably tells the tale of a succession of forests.

Before going on to a sketch of the early ages of the Earth's history—ages stretching back long long before the time of Adam—it is needful to think yet for a little longer about the manner in which that history is written, and the way in which it has to be read.

For the record is one difficult to make out, and its style of expression is often dark and mysterious. There is scarcely any other volume in the great Book of Nature which the student is so likely to misread as this one. It is very needful, therefore, to hold the conclusions of geologists with a light grasp, guarding each with a "perhaps" or a "may be." Many an imposing edifice has been built, in geology, upon a rickety foundation which has speedily given way.

In all ages of the world's history up to the present day, rock-making has taken place—fire-made rocks being fashioned underground, and water-made rocks being fashioned above ground though under water.

Also in all ages different kinds of rocks have been fashioned

side by side—limestone in one part of the world, sandstone in another, chalk in another, clay in another, and so on. There have, it is true, been ages when one kind seems to have been the *chief* kind—an age of limestone, or an age of chalk. But even then there were doubtless more rock-buildings going on, though not to so great an extent. On the other hand, there may have been ages during which no limestone was made, or no chalk, or no clay. As a general rule, however, the various sorts of rock-building have probably gone on together. This was not so well understood by early geologists as it is now.

The difficulty is often great of disentangling the different strata, and saying which was earlier and which later formed.

Still, by close and careful study of the rocks which compose the earth's crust, a certain kind of order is found to exist, more or less followed out in all parts of the world. *When* each layer was formed in England or in America, the geologist cannot possibly say. He can, however, assert, in either place, that a certain mass of rock was formed before a certain other mass in that same place, even though the two may seem to lie side by side; for he knows that they were so placed only by upheaval, and that once upon a time the one lay beneath the other.

The geologist can go further. He can often declare that a certain mass of rock in America and a certain mass of rock in England, quite different in kind, were probably built up at about the same time. How long ago that time was he would be rash to attempt to say; but that the two belong to the same age he has good reason for supposing.

We find rocks piled upon rocks in a certain order, so that we may generally be pretty confident that the lower rocks were first made, and the upper rocks the latest built. Further than this, we find in all the said layers of water-built rocks signs of past life.

As already stated, much of this life was ocean-life, though not all.

Below the sea, as the rock-layers were being formed, bit by bit, of earth dropping from the ocean to the ocean's floor, sea-creatures lived out their lives and died by thousands, to sink to that same floor. Millions passed away, dissolving and leaving

no trace behind; but thousands were preserved—shells often, animals sometimes.

Nor was this all. For now and again some part of the sea-bottom was upheaved, slowly or quickly, till it became dry land. On this dry land animals lived again, and thousands of them, too, died, and their bones crumbled into dust. But here and there one was caught in bog or frost, and his remains were preserved till, through lapse of ages, they turned to stone.

Yet again that land would sink, and over it fresh layers were formed by the ocean-waters, with fresh remains of sea-animals buried in with the layers of sand or lime; and once more the sea-bottom would rise, perhaps then to continue as dry land, until the day when man should discover and handle these hidden remains.

Now note a remarkable fact as to these fossils, scattered far and wide through the layers of stratified rock. In the uppermost and latest-built rocks the animals found are the same, in great measure, as those which now exist upon the earth.

Leaving the uppermost rocks, and examining those which lie a little way below we find a difference. Some are still the same, and others, if not quite the same, are very much like what we have now; but here and there a creature of a different form appears.

Go deeper still, and the kinds of animals change further. Fewer and fewer resemble those which now range the earth; more and more belong to other species.

Descend through layer after layer till we come to rocks built in earliest ages, and not one fossil shall we find precisely the same as one animal living now.

So not only are the rocks built in successive order, stratum after stratum belonging to age after age in the past, but fossil-remains also are found in successive order, kind after kind belonging to past age after age.

Although in the first instance the succession of fossils was understood by means of the succession of rock-layers, yet in the second place the arrangement of rock-layers is made more clear by the means of these very fossils.

A geologist, looking at the rocks in America, can say which

there were first-formed, which second-formed, which third-formed. Also, looking at the rocks in England, he can say which there were first-formed, second-formed, third-formed. He would, however, find it very difficult, if not impossible, to say which among any of the American rocks was formed at about the same time as any particular one among the English rocks, were it not for the help afforded him by these fossils.

Just as the regular succession of rock-strata has been gradually learned, so the regular succession of different fossils is becoming more and more understood. It is now known that some kinds of fossils are always found in the oldest rocks, and in them only; that some kinds are always found in the newest rocks, and in them only; that some fossils are rarely or never found lower than certain layers; that some fossils are rarely or never found higher than certain other layers.

So this fossil arrangement is growing into quite a history of the past. And a geologist, looking at certain rocks, pushed up from underground, in England and in America, can say: "These are very different kinds of rocks, it is true, and it would be impossible to say how long the building up of the one might have taken place before or after the other. But I see that in both these rocks there are exactly the same kinds of fossil-remains, differing from those in the rocks above and below. I conclude therefore that the two rocks belong to about the same great age in the world's past history, when the same animals were living upon the earth."

Observing and reasoning thus, geologists have drawn up a general plan or order of strata; and the whole of the vast masses of water-built rocks throughout the world have been arranged in a regular succession of classes, rising step by step from earliest ages up to the present time.

PHYSICAL GEOGRAPHY

The Atmosphere

By ELISHA GRAY

METEOROLOGY is a science that at one time included astronomy, but now it is restricted to the weather, seasons, and all phenomena that are manifested in the atmosphere in its relation to heat, electricity, and moisture, as well as the laws that govern the ever-varying conditions of the circumambient air of our globe. The air is made up chiefly of oxygen and nitrogen, in the proportions of about twenty-one parts of oxygen and seventy-nine parts nitrogen by volume, and by weight about twenty-three parts of oxygen and seventy-seven of nitrogen. These gases exist in the air as free gases and not chemically combined. The air is simply a mixture of these two gases.

There is a difference between a mixture and a compound. In a mixture there is no chemical change in the molecules of the substances mixed. In a compound there has been a rearrangement of the atoms, new molecules are formed, and a new substance is the result.

About ninety-nine and one-half per cent. of air is oxygen and nitrogen, and one-half per cent is chiefly carbon dioxide. Carbon dioxide is a product of combustion, decay, and animal exhalation. It is poison to the animal, but food for the vegetable. The proportion in the air is so small however, that its baneful influence upon animal life is reduced to a minimum. The nitrogen is an inert, odorless gas, and its use in the air seems to be to dilute it, so that man and animals can breathe it. If all the nitrogen were extracted from the air and only

the oxygen left to breathe, all animal life would be stimulated to death in a short time. The presence of the nitrogen prevents too much oxygen from being taken into the system at once.

Air contains more or less moisture in the form of vapor; this subject, however, will be discussed more fully under the head of evaporation. The air at sea-level weighs fifteen pounds to the square inch, and if the whole envelope of air were homogeneous—the same in character—it would reach only about five miles high. But as it becomes gradually rarefied as we ascend it probably extends in a very thin state to a height of eighty or ninety miles; at least, at that height we should find a more perfect vacuum than can be produced by artificial means. The weight of all the air on the globe would be eleven and two-thirds trillion pounds if no deduction had to be made for space filled by mountains and land above sea-level. As it is, the whole bulk weighs something less than the above figures.

The air envelopes the globe to a height at sea-level of eighty or ninety miles, gradually thinning out into the ether that fills all interstellar space. We live and move on the bottom of a great ocean of air. The birds fly in it just as the fish swim in the ocean of water. Both are transparent and both have weight. Water in the condensed state is heavier than the air and will seek the lowest places, but when vaporized, as in the process of evaporation, it is lighter than air and floats upward. In the vapor state it is transparent like steam. If you study a steam jet you will notice that for a short distance after it issues from the boiler it is transparent, but soon it condenses into cloud.

If we could see inside of a boiler in which steam had been generated, all the space not occupied with water would seem to be vacant, since steam, before it is condensed, is as transparent as the air. We will, however, speak of this subject more fully under the head of evaporation and cloud formation. It is not enough that we have the air in which we live and move, with all of its properties, as we have described: something more is needed which is absolutely essential both to animal and vegetable life—and this essential is motion. If the air remained

perfectly still with no lateral movement or upward and downward currents of any kind, we should have a perfectly constant condition of things subjected only to such gradual changes as the advancing and receding seasons would produce owing to the change in the angle of the sun's rays. No cloud would ever form, no rain would ever fall, and no wind would ever blow. It is of the highest importance not only that the wind shall blow, but that comparatively sudden changes of temperature take place in the atmosphere, in order that vegetation as well as animal life may exist upon the surface of the globe. The only place where animal life could exist would be in the great bodies of water, and it is even doubtful if water could remain habitable unless there were means provided for constant circulation—motion.

The mobility of the atmosphere is such that the least influence that changes its balance will put it in motion. While we can account in a general way for atmospheric movements, there are many problems relating to the details that are unsolved. We find that even the "weather man" makes mistakes in his prognostications; so true is this that it is never safe to plan a picnic for to-morrow based upon the predictions of to-day. The chief difficulty in the way of solving the great problems relating to the sudden changes in the weather and temperature lies in the fact that two-thirds or more of the earth's surface is covered with water; thus making it impossible to establish stations for observations that would be evenly distributed all over the earth's surface. Enough is known, however, to make the study of meteorology a most wonderfully interesting subject.

Air is composed chiefly of a mixture of oxygen and nitrogen, with a small amount of carbon dioxide. So far as the life and health of the animal is concerned we could get along without this latter substance, but it seems to be a necessity in the growth of vegetation. There are other things in the air which, while they are unnecessary for breathing purposes, it will be well for us to understand, as some of them are things to be avoided rather than inhaled.

As before mentioned, air contains moisture, which is a very variable quantity. In a cold day in winter it is not more than

one-thousandth part, while in a warm day in summer it may equal one-fortieth of the quantity of air in a given space. There is also a small amount of ammonia, perhaps not over one-sixty-millionth. Oxygen also exists in the air in very small quantities in another form called ozone. One way to produce ozone is by passing an electric spark through air. Any one who has operated a Holtz machine has noticed a peculiar smell attending the disruptive discharges, which is the odor of ozone. It is what chemists call an allotropic form of oxygen, just as the diamond, graphite, and charcoal are all different forms of carbon, and yet the chemical differences are scarcely traceable. It is more stimulating to breathe than oxygen, and is probably produced by lightning discharges.

The oxygen of the air is consumed by all processes of combustion, and in this we include the breathing of men and animals and the decay of vegetable matter, as well as the more active combustion arising from fires. A grown person consumes something over four hundred gallons of oxygen per day, and it is estimated that all the fires on the earth consume in a century as much oxygen as is contained in the air over an area of seventy miles square. All of these processes are throwing into the air carbon dioxide (carbonic acid), which, however, is offset by the power of vegetation to absorb it; thus the carbon is retained and forms a part of the woody fiber, and pure oxygen is given back into the air. By this process the normal conditions of the air are maintained.

One decimeter (nearly four inches) square of green leaves will decompose in one hour seven cubic centimeters of carbon dioxide, if the sun is shining on them; in the shade the same area will absorb about three in the same time.

The air contains another substance called bacteria in the form of vegetable germs. At one time these were supposed to be low forms of animal life, but it is now determined that they are the lowest forms of vegetable germs. Bacteria is the general or generic name for a large class of germs, many of them disease germs. By analysis of the air in different locations and in different parts of the country it has been determined that on the ocean and on the mountain tops these germs average only

one to each cubic yard of air. In the streets of the average city there are 3,000 of them to the cubic yard, while in other places where there is sickness, as in a hospital ward, there may be as many as 80,000 to the cubic yard. These facts go to prove what has long been well known, that the air of a city furnishes many more fruitful sources for disease than that of the country. Some forms of bacterial germs are not considered harmful, and they probably perform even a useful service in the economy of nature. Within certain limits, other things being equal, the higher one's dwelling is located above the common level the purer will be the air. This rule, however, has its limits, as the oxygen of the air is heavier than the nitrogen, so that the air at very great altitudes has not the same proportion of oxygen to nitrogen that it has at a lower level. An analysis that was made some years ago of the air on the west shore of Lake Michigan, especially that section where the bluffs are high, shows that it compares favorably with that of any other portion of the United States.

In view of the foregoing, it is of the highest importance to the sanitary condition of any city, town, or village that it be not too compactly built. If more than a certain number of people occupy a given area, it is absolutely impossible to preserve perfect sanitary conditions. And there ought to be a State law, especially for all suburban towns, which are the homes and sleeping places for large numbers of business men who spend their days in the foul air of the city, stipulating that the houses shall be not less than a certain distance apart. Oxygen is the great purifier of the blood, and if one does not get enough of it he suffers, even though he breathes no impurities. The power to resist the effects of bad air is much greater when one is awake and active than when asleep, and this is why it is more important to sleep in pure air than to be in it during our waking hours. It is best, however, to be in good air all of the time. By pure air I do not mean pure oxygen, but the right mixture of the two gases that make air. Too much of a good thing is often worse than not enough. Pure food to eat, pure water to drink, and pure air to breathe would soon be the financial ruin of a large class of doctors.

PHYSICAL GEOGRAPHY

Wind—Why It Blows

By ELISHA GRAY

GLOBULES of moisture, released by the action of the sun's rays in the process of evaporation, tend to rise, because they are lighter than the air. All material substances have weight; even hydrogen, the lightest known gas, has weight, and is attracted by gravitation. If there were no air or other gaseous substances on the face of the earth except hydrogen, it would be attracted to and envelop the earth the same as the air now does. Carbon dioxide is a gas that is heavier than the air. If we take a vessel filled with this gas and pour it into another vessel it will sink to the bottom and displace the air contained in it until the air is all driven out. If we fill a jar with water up to a certain height and then pour a pint of shot into it the water will be caused to rise in the vessel because it has been displaced at the bottom by the heavier material. Now if we remove the shot, the water will recede to the level maintained before the shot was put in. On the contrary, if we should pour an equal bulk of cork or pith balls into the jar, the water would not be displaced, because the balls are lighter than the water and would lie on top of it; if, however, the water is removed from the jar, the cork will immediately go to the bottom of the jar, because the cork is heavier than the air which has taken the place of the water. We wish to impress upon the mind of the reader the fact, that all substances of a fluid nature, whether in the fluid or gaseous state, have weight, and obey the laws of gravity, while the heavier portions will always seek the lower levels, and in doing this will displace the lighter



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THE POWER OF THE WIND.

(Results of a Tornado in Omaha, April, 1913.)

portions, causing them to rise. There is no tendency in any substance to rise of itself, but the lighter substance rises because it is forced to do so by the heavier, which displaces it. This law lies at the bottom of all the phenomena of air currents.

If we are at certain points on the seashore in the summer time we may notice that about nine o'clock in the morning a breeze will spring up from the ocean and blow toward the land; this will increase in intensity until about two o'clock in the afternoon, when it has reached its maximum velocity, and from this time it gradually diminishes, until in the evening there will be a season of calm, the same as there was in the early morning. The explanation of this peculiar action of the air is found in the fact that during the day the land is heated much more rapidly on its surface than the water is.

The radiant energy from the sun is suddenly arrested at the surface of the earth, which is heated to only a very shallow depth, while in the water it is different; being transparent it is penetrated by the radiant energy to a much greater depth and does not suddenly arrest it, as is the case on land. As the sun rises and the rays strike in a more and more vertical direction, the earth becomes rapidly and intensely heated at its surface, and this in turn heats the stratum of air next above it, which is pressing on it with a force of fifteen pounds to the square inch at sea-level. When air is heated it expands, and as it expands it grows lighter. The stratum lying upon the earth as soon as it becomes heated moves upward and its place is occupied by the heavier, cooler air that flows in from the sides. We can now see that if there is a strong ascending current of air on the land near the ocean the cooler air from the surface of the ocean will flow in to take the place of the warmer and lighter air that is driven upward, really by the force of gravity which causes the heavier fluid to keep the lowest level. As the earth grows hotter this movement is more and more rapid, which causes the flow of colder air to be quickened, and hence the increasing force of the wind as the sun mounts higher in the heavens. But when it has passed the point of maximum heating intensity and the earth begins to cool by radiation, the movements of air currents begin to slow up, until along in the

evening a point is reached where the surface of the earth and that of the ocean are of equal temperature, and there is no longer any cause for change of position in the air.

The earth heats up quickly, and it also cools quickly, especially if there is green grass and vegetation. While they are poor conductors of heat, they are excellent radiators, so that when the sun's rays are no longer active the earth cools down rapidly and soon passes the point where there is an equilibrium between the land and water. The water possesses the opposite quality. It is slow to become heated, because of a much larger mass that is affected, and is equally slow to give up the heat. And the consequence is, that after the sun has set the land cools so much faster than the water that we soon have the opposite condition, and the sea is warmer than the land, which makes the air at that point lighter, and which in turn causes the denser or colder air from the land to flow toward the ocean, and displace the lighter air and force it upward; hence we have a land instead of a sea breeze. So that the normal condition in summer is that of a breeze from the ocean toward the land during part of the day and a corresponding breeze from the land to the ocean during part of the night, with a period of no wind during the morning and evening of each day.

The forces that work to produce all the varying phenomena of air currents on different portions of the earth are difficult to explain, as there are so many local conditions of heat and cold, and these are modified by the advancing and receding seasons. The unequal distribution of land and water upon the earth's surface; the readiness with which some portions absorb and radiate heat as compared with others; the tall ranges of mountains, many of them snow-capped; the lowlands adjacent to them that become intensely heated under the sun's rays; the diversity of coast-line and the fact that there is a zone of continually heated earth and water in the tropical regions—all these conditions, coupled with the fact that the earth rotates on its axis once in twenty-four hours, are certainly sufficient to account for all the complicated phenomena of aerial changes on the various portions of the earth's surface.

The trade winds are so called because they blow in a certain

definite direction during certain seasons of the year, and can be reckoned upon for the use of commerce. If you trace the line of the equator you will notice that for more than three-quarters of the distance it passes through the water. The water becomes gradually heated to a considerable depth, and when once saturated with heat is slow to give it up. It can easily be seen that there will be a zone extending each way from the equator for a certain distance that will become more intensely heated than any other parts of the earth, with the exception of certain circumscribed portions of the land. The result is that this heated equatorial zone is constantly sending up warm air caused by the inrush of colder air, which is heavier than the air at the equator, expanded by the heat. The warm air at the equator is forced up into higher regions of the atmosphere, and here it overflows each way, north and south, causing a current of air in the upper regions counter to that of the lower. As it travels north and south it gradually drops as it becomes cooler, and finally at some point north and south its course is changed and it flows in again toward the equator. As a matter of fact, the trade winds do not flow apparently from the north and south directly toward the equator, but in an oblique direction. On the north side of the equator we have a northeasterly wind, and a southeasterly wind on the south side. This is caused by the rotation of the earth from west to east. The direction of the trade wind, however, is more apparent than real.

The earth in its diurnal revolutions travels at the rate of a little more than 1,000 miles an hour at the equator. But if we should travel northward to within four miles, say, of the north pole, the surface point would be moving at the rate of only about a mile an hour. At some point equidistant between the north pole and the equator the surface of the earth will be moving at a rate, say, of five hundred miles an hour. If we could fire a projectile from this point that would have a carrying power to take it to the equator some time after the projectile was fired, although it would fly in a perfectly direct line, it would appear to any one at the equator to be moving from a northeasterly direction. The reason is that the earth is travel-

ing twice as fast at the equator as it is at the point whence the projectile is fired. Therefore it will overshoot, so to speak, at the equator, and not be dragged around by the increased motion we find there.

To make this still plainer, suppose the earth to be standing still and a projectile be fired directly across from the north pole in the direction of the lines of longitude and required one hour to reach the equator, the projectile would appear to any one standing at the equator to come directly from the north. If, however, the earth is revolving to the eastward at the rate of 1,000 miles an hour at the equator, and the projectile was fired from the pole, where there is practically no motion, in the same direction along the longitudinal lines as before, the observer would have to be in a position of the equator 1,000 miles west of this longitudinal line, in order to see the projectile when it arrived; therefore the apparent movement of the projectile would not be along the line at the instant that it was fired, but along a line that would cross the equator at a point 1,000 miles west. When a southward impulse is given to the air it follows, to some extent, the same law, so that to one standing on the equator the northern trade wind will blow from the northeast and the southern trade wind from the southeast.

Owing to the fact that the air rises in the heated zone there is always a region of calms at this point where there is no wind and no rain. There are two other regions of calms in the ocean, one at the north at the tropic of Cancer and another at the south near the tropic of Capricorn. As has been stated, there are currents flowing back in the upper regions at the equator north and south, and these are called the upper trades—the lower currents being called the lower trades. These upper trades gradually fall till they reach the tropic of Cancer on the north, where the lower part of the current stops and bends back toward the equator, now becoming a part of the lower trade wind. This causes a calm at that point where it turns. The upper parts of this current continue on, in a northerly and southerly direction, on the surface until they meet with the cold air of the north and south polar regions,

where there is a conflict of the elements—as there always is when cold and warm currents meet.

The only point where the trade wind has free play is in the South Indian Ocean, and this is called the “heart of the trades.”

If the whole globe were covered with water there would be a more constant condition of temperature; but owing to the great difference between the land and water, both as to altitude and the ability to absorb and radiate heat, we have all of these varied and complicated conditions of wind and weather. The trade winds shift from north to south and vice versa with the advancing and receding seasons, due to the fact that the earth has a compound motion. It not only revolves on its axis once in twenty-four hours, but it also travels around the sun once a year; and because the axis of the earth is not perpendicular to the plane of its orbit around the sun, the earth seems to rock back and forth in the direction of its axis once a year. This is only apparent, however, and not real.

PHYSICAL GEOGRAPHY

Mirage

By ELISHA GRAY

A LIGHT-RAY in passing from one transparent medium to another, differing in density, is bent at the point it enters. This bending of the light-ray is called refraction. If we put a stick into the water at an angle with its surface the stick will appear to bend upward at the point it enters the water, while the light-ray really bends downward.

To illustrate this phenomenon place a tank, something like an aquarium, filled with water, in a dark room. Admit a small beam of sunshine through the shutter, striking the top of the water at an angle, say, of forty-five degrees. If the room is dark you can see the beam of light as it passes through the air, for it illuminates the particles of dust floating in the air. When it strikes the surface of the water it is bent downward. Now let us put a coin on the bottom of the tank just where the beam of light strikes it, and put a screen of some opaque substance on the side of the tank from which the beam of light comes, and raise it up till it just touches the lower edge of the light-ray. Stretch a string along the path of the beam of light and fasten it at both ends—so as to mark its angle and position. Now open the shutter and flood the room with light; place your eye in the path of the beam that is now marked by the string and you can see the coin at the bottom of the tank, although it is really hidden by the screen, if you look toward it in a straight line. The coin will appear to be in a direct line with the string, but it is not.

Leave the string, coin, and screen in position, and run the

water off, and then place your eye in the same position as before when you saw the coin, and you will find that you cannot see it, for it is hidden behind the screen. Draw a line to the bottom of the tank in line with the string, and the point where it strikes the bottom is where the coin appeared to be. Place another coin at this point so that you can just see it over the top of the screen if you look from the same point as before. Now fill the tank with water again and look from the same view-point, and lo! the first coin has come into view in line with the string, while the second has moved forward out of line with the string. You observe, then, that by this means we can see around a corner. But the object under these conditions is never where it appears to be, for it will always appear to be in a direct line with the direction that the light-ray—that is reflected from the object—enters the eye.

Light is refracted differently in different media. It is refracted as it passes through the air unless the air is the same density all the way from the object to the eye. If we are looking through the air and there is a gradual change of density between us and the object we see, there will be a gradual curve in the reflected light coming from the object to us, and the object will appear to be in the direction that the light enters our eyes. The distance its true position will be from where it appears to be will depend upon the amount of change in the density of the media through which we are looking. This phenomenon we call mirage. Many times those of us who live on the lakeshore have seen this phenomenon when looking off on the horizon on a summer day. Sometimes the sand-hills of Michigan City, on the east shore of Lake Michigan, may be seen from the opposite shore looming up in the air, when in fact a straight line drawn from a point on the shore at Michigan City and elevated just enough to clear the surface of the water would clear the tree-tops on the opposite shore. So that when we see the sand-hills from the west shore we see by curved rays of light extending across the lake. Sometimes an image of the water-line on the horizon will be thrown up into the air with perhaps a picture of a ship on it, and often we can see the sky under the ship-picture, but not the ship itself, of which that

is a reflection. Many times we see the sun after it is below the horizon, by these refracted rays.

There is another phenomenon called mirage, that may be seen on sandy plains or deserts on any very hot day. The sand becomes very much heated, and a stratum of heated air is formed close to the ground which makes the density of the air increase upward, for a distance, forming a line of condensation which acts as a reflecting surface for light, and it has the appearance of smooth water. Any one seeing it for the first time will declare that it is water, and in fact the deception is perfect, as I have occasion to know. I was once traveling through what is called Smoky Valley, in Nevada, on a hot day. About two o'clock in the afternoon we came in sight of a large body of water many miles in extent, as it appeared to me. It was a lake of wondrous beauty, with a smooth surface. The mountains and trees were reflected in the water in inverted position, as all of us have seen in other bodies of smooth water. I imagined that I could see towns and cities scattered along the distant shores, and the deception was so perfect that for the time I could not believe it was not what it seemed. My companions were natives, and, knowing that I was a "tenderfoot," were disposed to have a little fun; and they had it. They had names for the towns, as well as the lake, and I got a lot of information regarding the industries carried on there. I could discern sails in the haze of the distance, and imagined I could see moving trains and hear the whistle of locomotives. After I had enjoyed this spectacle for an hour or more, as we jogged slowly along in our wagon, and the natives had had untold fun in a quiet way, the whole thing suddenly picked itself up and got out of sight. I knew then that I had been witnessing an unusually fine exhibition of mirage on the desert.

There is another kind of mirage that is much more common than the natural phenomena that I have been describing, and while it does not strictly belong in the category of natural science, there is a sense in which it does. It may be styled mental mirage, and consists in the distorted conceptions of various subjects and things that we see through a distorted mental atmosphere, which is largely one of our own creation.

Man is to a large extent a creature of circumstances and environment; not wholly, as that would take away his free agency and make him in no sense the architect of his own fortune. Every man of strong individuality is the latter, to a large extent, but he is a strong man indeed who can successfully resist, first, the molding influence of heredity, and after that the almost irresistible power of education in any particular line. He cannot entirely resist the prejudices of early training and surroundings, whether they appeal to his reasoning powers or not. This is especially true when applied to the dogmas of religious sects and the so-called principles of political parties. The average good citizen of any religious sect or political party sees clearly, in common with his brethren of other sects and parties, in direct lines through the atmosphere of common interest, common brotherhood, and sometimes common sense. But as soon as the rays of his mental vision strike some denser, or, it may be, rarer medium of prejudice of party, church, or society affiliation, a refraction takes place, and we have the phenomenon of mental mirage. The truth may lie in a direct line ahead, but he is really seeing in a different direction because of the refracting or distorting power of a prejudice.

Science has no prejudices—though scientists often do. Science is like figures: they do not lie themselves, but the men who figure are often the greatest liars in the world. Science, *per se*, is formulated truth. Its aim is to get at the truth about everything. Taking this view of science, it is the most important study that man ever engaged in. So much of human effort has been and is spent in combating things that are non-essential, that too little co-operative work is done in the direction of determining the great essential truths. In one of the chapters on Sound it was shown how one musical tone of the same power and pitch, and even of the same quality, as that of another just like it, might be entirely obliterated by the manner in which they were sounded in relation to each other. It was also shown that there was an easier way to sound both together so that each would re-enforce the other and thus double the tone instead of the one entirely destroying the efficiency of the other. So it is with human effort. Co-operation will ac-

comply with wonders for good, while the opposite only leaves a dark void that is the darker because of the misguided effort put forth, that other men have not only seen, but of which they have also felt the blighting influence.

Another phase of mirage, as seen in natural phenomena, is its complete deceptiveness and its ability, owing to the peculiar atmosphere by which it is surrounded, to stimulate the imagination. In the hazy outlines ghosts of shapes become real things, and the heated wave-motion of the atmosphere easily gives life to imaginary men and animals and motion to sailing vessels and steam-cars. Mental mirage is more potent in its deceptiveness and more powerful in its influence over the imagination than its counterpart in the natural world; and has the disadvantage of not yielding so readily to the power of analysis and being so susceptible of explanation. One of the great advantages derived from the study of natural science is, that it is usually studied for its own sake and for the object of arriving at the truth whatever it is. The scientific investigator must have no prejudice not founded on fact, and when so founded it is no longer a prejudice. He must not allow the religious dogma or the political principle to enter or become one of the factors in his search for truth, but when he has found the truth it may shape the dogma, destroy or confirm the political principle, according as they are found to be in or out of harmony with the facts. Facts are stubborn things, and it is worse than useless to try to ignore them when once established. The man who uses scientific methods in studying all questions is a much safer man to follow than the man who starts out with certain preconceived notions of things. The former throws away all prejudice in his investigations, while the latter is constantly trying to find something to bolster up his preconceived notions. He generally thinks he finds what he is seeking for, but he usually finds them through the refracted vision of mental mirage.

PHYSICAL GEOGRAPHY

Rain and Snow

By JOHN TYNDALL

AT the equator, and within certain limits north and south of it, the sun at certain periods of the year is directly overhead at noon. These limits are called the Tropics of Cancer and of Capricorn. Upon the belt comprised between these two circles the sun's rays fall with their mightiest power; for here they shoot directly downward, and heat both earth and sea more than when they strike slantingly.

When the vertical sunbeams strike the land they heat it, and the air in contact with the hot soil becomes heated in turn. But when heated the air expands, and when it expands it becomes lighter. This lighter air rises, like wood plunged into water, through the heavier air overhead.

When the sunbeams fall upon the sea the water is warmed, though not so much as the land. The warmed water expands, becomes thereby lighter, and therefore continues to float upon the top. This upper layer of water warms to some extent the air in contact with it, but it also sends up a quantity of aqueous vapor, which being far lighter than air, helps the latter to rise. Thus both from the land and from the sea we have ascending currents established by the action of the sun.

When they reach a certain elevation in the atmosphere, these currents divide and flow, part toward the north and part toward the south; while from the north and the south a flow of heavier and colder air sets in to supply the place of the ascending warm air.

Incessant circulation is thus established in the atmosphere.

The equatorial air and vapor flow above toward the north and south poles, while the polar air flows below toward the equator. The two currents of air thus established are called the upper and the lower trade winds.

But before the air returns from the poles great changes have occurred. For the air as it quitted the equatorial regions was laden with aqueous vapor, which could not subsist in the cold polar regions. It is there precipitated, falling sometimes as rain, or more commonly as snow. The land near the pole is covered with this snow, which gives birth to vast glaciers.

It is necessary that you should have a perfectly clear view of this process, for great mistakes have been made regarding the manner in which glaciers are related to the heat of the sun

It was supposed that if the sun's heat were diminished, greater glaciers than those now existing would be produced. But the lessening of the sun's heat would infallibly diminish the quantity of aqueous vapor, and thus cut off the glaciers at their source. A brief illustration will complete your knowledge here.

In the process of ordinary distillation, the liquid to be distilled is heated and converted into vapor in one vessel, and chilled and reconverted into liquid in another. What has just been stated renders it plain that the earth and its atmosphere constitute a vast distilling apparatus in which the equatorial ocean plays the part of the boiler, and the chill regions of the poles the part of the condenser. In this process of distillation *heat* plays quite as necessary a part as *cold*, and before Bishop Heber could speak of "Greenland's icy mountains," the equatorial ocean had to be warmed by the sun. We shall have more to say upon this question afterward.

The heating of the tropical air by the sun is *indirect*. The solar beams have scarcely any power to heat the air through which they pass; but they heat the land and ocean, and these communicate their heat to the air in contact with them. The air and vapor start upward charged with the heat thus communicated.

TROPICAL RAINS

But long before the air and vapor from the equator reach the poles, precipitation occurs. Wherever a humid warm wind mixes with a cold dry one, rain falls. Indeed the heaviest rains occur at those places where the sun is vertically overhead. We must inquire a little more closely into their origin.

Fill a bladder about two-thirds full of air at the sea level, and take it to the summit of Mount Blanc. As you ascend, the bladder becomes more and more distended; at the top of the mountain it is fully distended, and has evidently to bear a pressure from within. Returning to the sea level you find that the tightness disappears, the bladder finally appearing as flaccid as at first.

The reason is plain. At the sea level the air within the bladder has to bear the pressure of the whole atmosphere, being thereby squeezed into a comparatively small volume. In ascending the mountain, you leave more and more of the atmosphere behind; the pressure becomes less and less, and by its expansive force the air within the bladder swells as the outside pressure is diminished. At the top of the mountain the expansion is quite sufficient to render the bladder tight, the pressure within being then actually greater than the pressure without. By means of an air-pump we can show the expansion of a balloon partly filled with air, when the external pressure has been in part removed.

But why do I dwell upon this? Simply to make plain to you that the *unconfined air*, heated at the earth's surface, and ascending by its lightness, must expand more and more the higher it rises in the atmosphere.

And now I have to introduce to you a new fact, toward the statement of which I have been working for some time. It is this: *The ascending air is chilled by its expansion.* Indeed this chilling is one source of the coldness of the higher atmospheric regions. And now fix your eye upon those mixed currents of air and aqueous vapor which rise from the warm tropical ocean. They start with plenty of heat to preserve the vapor

as vapor; but as they rise they come into regions already chilled, and they are still further chilled by their own expansion. The consequence might be foreseen. The load of vapor is in great part precipitated, dense clouds are formed, their particles coalesce to rain-drops, which descend daily in gushes so profuse that the word "torrential" is used to express the copiousness of the rainfall. I could show you this chilling by expansion, and also the consequent precipitation of clouds.

Thus, long before the air from the equator reaches the poles, its vapor is in great part removed from it, having redescended to the earth as rain. Still a good quantity of the vapor is carried forward, which yields hail, rain, and snow in northern and southern lands.

MOUNTAIN CONDENSERS

To complete our view of the process of atmospheric precipitation we must take into account the action of mountains. Imagine a southwest wind blowing across the Atlantic toward Ireland. In its passage it charges itself with aqueous vapor. In the south of Ireland it encounters the mountains of Kerry; the highest of these is Magillicuddy's Reeks, near Killarney. Now the lowest stratum of this Atlantic wind is that which is most fully charged with vapor. When it encounters the base of the Kerry mountains it is tilted up and flows bodily over them. Its load of vapor is therefore carried to a height, it expands on reaching the height, it is chilled in consequence of the expansion, and comes down in copious showers of rain. From this, in fact, arises the luxuriant vegetation of Killarney; to this, indeed, the lakes owe their water supply. The cold crests of the mountains also aid in the work of condensation.

Note the consequence. There is a town called Cahirciveen to the southwest of Magillicuddy's Reeks, at which observations of the rainfall have been made, and a good distance farther to the northeast, right in the course of the southwest wind there is another town, called Portarlinton, at which observations of rainfall have also been made. But before the wind reaches the latter station it has passed over the mountains of Kerry and left a great portion of its moisture behind it. What is the re-

sult? At Cahirciveen, as shown by Dr. Lloyd, the rainfall amounts to fifty-nine inches in a year, while at Portarlinton it is only twenty-one inches.

Again, you may sometimes descend from the Alps when the fall of rain and snow is heavy and incessant, into Italy, and find the sky over the plains of Lombardy blue and cloudless, the wind at the same time *blowing over the plain toward the Alps*. Below, the wind is hot enough to keep its vapor in a perfectly transparent state; but it meets the mountains, is tilted up, expanded, and chilled. The cold of the higher summits also helps the chill. The consequence is that the vapor is precipitated as rain or snow, thus producing bad weather upon the heights, while the plains below, flooded with the same air, enjoy the aspect of the unclouded summer sun. Clouds blowing *from* the Alps are also sometimes dissolved over the plains of Lombardy.

In connection with the formation of clouds by mountains, one particularly instructive effect may be here noticed. You frequently see a streamer of cloud many hundred yards in length drawn out from an Alpine peak. Its steadiness appears perfect, though a strong wind may be blowing at the same time over the mountain head. Why is the cloud not blown away? It *is* blown away; its permanence is only apparent. At one end it is incessantly dissolved; at the other end it is incessantly renewed: supply and consumption being thus equalized, the cloud appears as changeless as the mountain to which it seems to cling. When the red sun of the evening shines upon these cloud-streamers they resemble vast torches with their flames blown through the air.

ARCHITECTURE OF SNOW

We now resemble persons who have climbed a difficult peak, and thereby earned the enjoyment of a wide prospect. Having made ourselves masters of the conditions necessary to the production of mountain snow, we are able to take a comprehensive and intelligent view of the phenomena of glaciers.

A few words are still necessary as to the formation of snow.

The molecules and atoms of all substances, when allowed free play, build themselves into definite and, for the most part, beautiful forms called crystals. Iron, copper, gold, silver, lead, sulphur, when melted and permitted to cool gradually, all show this crystallizing power. The metal bismuth shows it in a particularly striking manner, and when properly fused and solidified, self-built crystals of great size and beauty are formed of this metal.

If you dissolve saltpetre in water, and allow the solution to evaporate slowly, you may obtain large crystals, for no portion of the salt is converted into vapor. The water of our atmosphere is fresh though it is derived from the salt sea. Sugar dissolved in water, and permitted to evaporate, yields crystals of sugar-candy. Alum readily crystallizes in the same way. Flints dissolved, as they sometimes are in nature, and permitted to crystallize, yield the prisms and pyramids of rock crystal. Chalk dissolved and crystallized yields Iceland spar. The diamond is crystallized carbon. All our precious stones, the ruby, sapphire, beryl, topaz, emerald, are all examples of this crystallizing power.

You have heard of the force of gravitation, and you know that it consists of an attraction of every particle of matter for every other particle. You know that planets and moons are held in their orbits by this attraction. But gravitation is a very simple affair compared to the force, or rather forces, of crystallization. For here the ultimate particles of matter, inconceivably small as they are, show themselves possessed of attractive and repellent poles, by the mutual action of which the shape and structure of the crystal are determined. In the solid condition the attracting poles are rigidly locked together; but if sufficient heat be applied the bond of union is dissolved, and in the state of fusion the poles are pushed so far asunder as to be practically out of each other's range. The natural tendency of the molecules to build themselves together is thus neutralized.

This is the case with water, which as a liquid is to all appearance formless. When sufficiently cooled the molecules are brought within the play of the crystallizing force, and they then arrange themselves in forms of indescribable beauty.

When snow is produced in calm air, the icy particles build themselves into beautiful stellar shapes, each star possessing six rays. There is no deviation from this type, though in other respects the appearances of the snow-stars are infinitely various. In the polar regions these exquisite forms were observed by Dr. Scoresby, who gave numerous drawings of them. I have observed them in mid-winter filling the air, and loading the slopes of the Alps. But in England they are also to be seen, and all words of mine must fail to convey an impression of their vivid beauty.

It is worth pausing to think what wonderful work is going on in the atmosphere during the formation and descent of every snow-shower; what building power is brought into play! and how imperfect seem the productions of human minds and hands when compared with those formed by the blind forces of nature!

But who ventures to call the forces of nature blind? In reality, when we speak thus we are describing our own condition. The blindness is ours; and what we really ought to say, and to confess, is that our powers are absolutely unable to comprehend either the origin or the end of the operations of nature.

But while we thus acknowledge our limits, there is also reason for wonder at the extent to which science has mastered the system of nature. From age to age, and from generation to generation, fact has been added to fact, and law to law, the true method and order of the Universe being thereby more and more revealed. In doing this science has encountered and overthrown various forms of superstition and deceit, of credulity and imposture. But the world continually produces weak persons and wicked persons; and as long as they continue to exist side by side, as they do in this our day, very debasing beliefs will also continue to infest the world.

ATOMIC POLES

“What did I mean when, a few moments ago I spoke of attracting and repellent poles?” Let me try to answer this question. You know that astronomers and geographers speak

of the earth's poles, and you have also heard of magnetic poles, the poles of a magnet being the points at which the attraction and repulsion of the magnet are as it were concentrated.

Every magnet possesses two such poles; and if iron filings be scattered over a magnet, each particle becomes also endowed with two poles. Suppose such particles devoid of weight and floating in our atmosphere, what must occur when they come near each other? Manifestly the repellent poles will retreat from each other, while the attractive poles will approach and finally lock themselves together. And supposing the particles, instead of a single pair, to possess several pairs of poles arranged at definite points over their surfaces; you can then picture them, in obedience to their mutual attractions and repulsions, building themselves together to form masses of definite shape and structure.

Imagine the molecules of water in calm cold air to be gifted with poles of this description, which compel the particles to lay themselves together in a definite order, and you have before your mind's eye the unseen architecture which finally produces the visible and beautiful crystals of the snow. Thus our first notions and conceptions of poles are obtained from the sight of our eyes in looking at the effects of magnetism; and we then transfer these notions and conceptions to particles which no eye has ever seen. The power by which we thus picture to ourselves effects beyond the range of the senses is what philosophers call the Imagination, and in the effort of the mind to seize upon the unseen architecture of crystals, we have an example of the "scientific use" of this faculty. Without imagination we might have *critical* power, but not *creative* power in science.

ARCHITECTURE OF LAKE ICE

We have thus made ourselves acquainted with the beautiful snow-flowers self-constructed by the molecules of water in calm, cold air. Do the molecules show this architectural power when ordinary water is frozen? What, for example, is the structure of the ice over which we skate in winter? Quite as wonderful as the flowers of the snow. The observation is rare, if not

new, but I have seen in water slowly freezing six-rayed ice-stars formed, and floating free on the surface. A six-rayed star, moreover, is typical of the construction of all our lake ice. It is built up of such forms wonderfully interlaced.

Take a slab of lake ice and place it in the path of a concentrated sunbeam. Watch the track of the beam through the ice. Part of the beam is stopped, part of it goes through; the former produces internal liquefaction; the latter has no effect whatever upon the ice. But the liquefaction is not uniformly diffused. From separate spots of the ice little shining points are seen to sparkle forth. Every one of those points is surrounded by a beautiful liquid flower with six petals.

Ice and water are so optically alike that unless the light falls properly upon these flowers you cannot see them. But what is the central spot? A vacuum. Ice swims on water because, bulk for bulk, it is lighter than water; so that when ice is melted it shrinks in size. Can the liquid flowers then occupy the whole space of the ice melted? Plainly no. A little empty space is formed with the flowers, and this space, or rather its surface, shines in the sun with the luster of burnished silver.

In all cases the flowers are formed parallel to the surface of freezing. They are formed when the sun shines upon the ice of every lake; sometimes in myriads, and so small as to require a magnifying glass to see them. They are always attainable, but their beauty is often marred by internal defects of the ice. Every one portion of the same piece of ice may show them exquisitely, while a second portion shows them imperfectly.

Here we have a reversal of the process of crystallization. The searching solar beam is delicate enough to take the molecules down without deranging the order of their architecture. Try the experiment for yourself with a pocket-lens on a sunny day. You will not find the flowers confused; they all lie parallel to the surface of freezing. In this exquisite way every bit of the ice over which our skaters glide in winter is put together.

I said that a portion of the sunbeam was stopped by the ice and liquefied it. What is this portion? The dark heat of the sun. The great body of the light waves, and even a portion of the dark ones, pass through the ice without losing any of their

heating power. When properly concentrated on combustible bodies, even after having passed through the ice, their burning power becomes manifest.

And the ice itself may be employed to concentrate them. With an ice-lens in the polar regions Dr. Scoresby has often concentrated the sun's rays so as to make them burn wood, fire gunpowder, and melt lead; thus proving that the heating power is retained by the rays, even after they have passed through so cold a substance.

By rendering the rays of the electric lamp parallel, and then sending them through a lens of ice, we obtain all the effects which Dr. Scoresby obtained with the rays of the sun.

PHYSICAL GEOGRAPHY

Tides

By ELISHA GRAY

ANY one who has spent a summer at the seashore has observed that the water level of the ocean changes twice in about twenty-four hours, or perhaps it would be a better statement to say that it is continually changing, and that twice in twenty-four hours there is a point when it reaches its highest level and another when it reaches its lowest. It swings back and forth like a pendulum, making a complete oscillation once in twelve hours. When we come to study this phenomenon closely we find that it varies each day, and that for a certain period of time the water will reach a higher level each succeeding day until it culminates in a maximum height, when it begins to gradually diminish from day to day until it has reached a minimum. Here it turns and goes over the same round again. It will be further observed that the time occupied between one high tide and the next one is a trifle over twelve hours. That is to say, the two ebbs and flows that occur each day require a little more than twenty-four hours, so that the tidal day is a little longer than the solar day. It corresponds to what we call the lunar day.

The moon goes through all its phases once in twenty-eight days. The tide considered in its simplest aspect is a struggle on the part of the water to follow the moon. There is a mutual attraction of gravitation between the earth and the moon. Because the water of the earth is mobile it tends to pile up at a point nearest the moon. But the earth as a whole also moves toward the moon, and more than the water does, keeping its

round shape, while its movable water (practically enveloping it) is piled up before it toward the moon and left accumulated behind it away from the moon. So that in a rough way it is a solid round earth, surrounded by an oval body of water: the long axis of the oval representing the high tides, which, as they follow the moon, slide completely around the earth once in every twenty-four hours. Thus, there are really two high tides and two low tides moving around the earth at the same time; and this accounts for the two daily tides.

We have accounted for the time when they occur in the fact that the water attempts to follow the moon, but this does not account for the gradual changes in the amount of fluctuation from day to day. The problem is complicated by the fact that the sun also has an attraction for the earth as well as the moon. But from the fact that the sun is something like four hundred times farther from the earth than the moon is, and also the fact that the attraction of one body for another varies inversely as the square of the distance, the moon has an immense advantage over the sun, although so much smaller. If the power of the moon were entirely suspended, or if the moon were blotted out of existence, there would still be a tide. The fluctuation between high and low tide would not be nearly so great as it is at present, but it would occur at the same time each day, because it would be wholly a product of the sun.

It will be easily seen that these two forces acting upon the water at the same time will cause a complicated condition in the movement of the waters of the ocean. There will come a time once in twenty-eight days when the sun and the moon will act conjointly, and both will pull in the same direction at the same time upon the water. This joint action of the sun and moon produces the highest tide, which is called the "spring" tide. From this point, however, the tides will grow less each day, because the relation of the sun and moon is constantly changing, owing to the fact that it requires three hundred and sixty-five days for the sun to complete his apparent revolution around the earth, while the moon does her actual course in twenty-eight days. When the sun and moon have changed their relative positions so that they are at right angles to each

other with reference to the earth—at a quarter-circle apart—the sun and moon will be pulling against each other; at least this is the point where the moon is at the greatest disadvantage with reference to its ability to attract the water.

Because one-quarter around the earth the sun is creating his own tide, which to that extent counteracts the effect produced by the moon, the tide under the moon at this point is at its lowest point and is called the “neap” tide. When the moon has passed on around the earth to a point where it is opposite to that of the sun—at a half-circle apart—there will be another spring tide, and then another neap tide when it is on the last quarter, and from that point the tide will increase daily until it reaches the point where the sun and moon are in exact line with reference to the earth’s center, when another spring tide occurs. From this it will be seen that there are two spring tides and two neap tides in each twenty-eight days. This is the fundamental law governing tides.

There are many other conditions that modify tidal effects. Neither the sun nor the moon is always at the same distance from the earth, so that there will be a variation, at times, in high and low tides. For instance, it will happen sometimes that when the sun and moon are acting conjointly they will both be at their nearest point to the earth, and when this is the case the spring tide will be much higher than usual.

For many years the writer has observed that artesian wells, made by deep borings of small diameter into the earth to a water supply, have a daily period of ebb and flow, as well as a neap and spring tide, the same as the tides of the ocean, except that the process is reversed. The time of greatest flow of an artesian well will occur at low tide in the ocean. This might be accounted for from the fact that when the tide is at its height the moon is also pulling upon the crust of the earth, which would tend to take the pressure off the sand rock which lies one or two thousand feet below the surface, and through which the flow of water comes, and thus slacken the flow. When the moon is in position for low tide, the crust of the earth would settle back and thus produce a greater pressure upon the water-bearing rock. This is the only theory that has

suggested itself to the writer that would seem to account for these phenomena.

Looked at from one standpoint, it is easy to account for tidal action. But when we attempt to make up a table giving the hour and minute as well as the height of the tide at that particular time we find that we have a very complicated mathematical problem. Tables are made out, however, so that we know at just what time in the day a tide will occur every day in the year.

PHYSICAL GEOGRAPHY

Why Ice Floats

By ELISHA GRAY

NATURE is full of surprises. By a long series of experimental investigations you think you have established a law that is as unalterable as those of the Medes and Persians. But once in a while you stumble upon phenomena that seem to contradict all that has gone before.

These, however, may be only the exceptions that prove the rule. It is recognized as a fundamental law that heat expands and cold contracts; that the atom when in a state of intense motion (which is the condition producing the effect that we call "heat") requires more room than when its motions are of a less amplitude. In other words, an increase in the amplitude of atomic motion is heating, while a decrease is cooling. It follows from the above statement that the colder a body becomes the smaller will be its dimensions. There are two or three, and perhaps more, exceptions to this rule, and the most notable one is that of water. Water follows the same law that all other substances do under the action of heat and cold, within certain limits only. If we take water, say at fifty degrees Fahrenheit and subject it to cold it will gradually contract in bulk until it reaches thirty-nine degrees Fahrenheit. At this point, very curiously, contraction ceases, and here we find the maximum density of water. If the temperature is still lowered we find the bulk is gradually increasing instead of diminishing (as is the rule with other fluids), and when it reaches the freezing point there is a sudden and marked expansion, so much so that a cubic foot of ice, which is solidified water, will not weigh

as much as a cubic foot of water before it freezes—hence it floats.

Let us try an experiment. Take a small glass flask, terminating in a long neck, say of four to six inches, and of small diameter. Suppose the water in the glass to be at fifty degrees Fahrenheit. Fill the flask with water until it stands halfway up the neck at fifty degrees temperature. Now immerse the flask gradually in hot water, and observe the effect. For a moment the water will lower in the neck of the tube, but this is due to the fact that the glass expands before the heat is communicated to the water and enlarges its capacity. But immediately the water will begin to rise as the heat is communicated to it, and will continue to expand up to the boiling point. Now take the flask out of the hot water and gradually introduce it into a freezing mixture made of broken ice and salt. Immediately the water will begin to fall in the tube, showing that it is contracting under the cold, and it will continue to contract until it reaches a temperature of thirty-nine degrees Fahrenheit, when it will come to a standstill and then proceed to expand as the temperature of the water lowers. When it reaches the freezing point the fluid can no longer rise in the neck of the flask, which is broken by the sudden expansion that takes place at this point.

To show what an irresistible power resides in the atoms of which the body is made, let us take an iron flask with walls one-half inch or more in thickness; fill it with water and seal it up by screwing on the neck an iron cap; now plunge it into the freezing mixture, and the first effect will be to contract the water unless it is already below thirty-nine degrees Fahrenheit, but when it reaches that point expansion sets in, and this continues to the freezing point, when a greatly increased expansion takes place suddenly. The walls of the iron flask, although a half-inch in thickness, are no longer able to resist the combined efforts of the billions upon billions of the atoms of which the water is made up, in their individual clamor for more room, hence the flask is shattered into pieces.

There are one or two other substances which are exceptions to the general rule, but we will mention only one, which is the

metal bismuth. If we should melt a sufficient amount to fill an iron flask such as we have described, and subject it to the same freezing process, the flask will be broken the same as in the experiment made with the water.

A query arises, Why this phenomenon? Why does water, in cooling, follow a different law from that of nearly all other substances?

This is a case where it is much easier to ask a question than to answer it. When water solidifies at the moment of freezing, crystallization sets in. But what is crystallization? Crystallization is a peculiar arrangement of the molecules of matter, which takes place in some substances when they pass from the liquid to the solid form. The molecules assume definite forms and shapes, according to the nature of the substance. When water assumes the solid form under the action of cold the molecules arrange themselves according to certain definite and fixed laws, the result of which is to increase the bulk to a considerable extent over that which the same number of molecules would occupy at a temperature of thirty-nine degrees Fahrenheit. Hence, as has been heretofore stated, a given block of solidified water is lighter than the same bulk would be in the fluid state, and this is the reason why ice floats.

What would happen in case nature did not make this exception to the laws of expansion and contraction by heat and cold, in the case of water? First, our lakes would freeze from the bottom upward; as soon as the surface became frozen, or even colder than the water underneath, it would drop to the bottom, the warmer water below coming up by a well-known law—that the warmer fluid rises and the colder falls. This circulation would continue until ice began to form, which would immediately drop to the bottom, and this process would go on until the whole mass were frozen solid. In the same way our rivers in the northern climates would freeze from the bottom, and in time our valleys would fill up with ice to a thickness that the summer's sun would never melt, and gradually all north of a certain zone would become a great glacier, rendering not only the lakes and rivers, but also the surface of the earth, unfitted for animal life.

PHYSICAL GEOGRAPHY

Franklin's Kite Modernized

By ALEXANDER McADIE

THE recent improvements in kites have suggested perhaps to many the question, "How would Franklin perform his kite experiment to-day?" It may seem a little presumptuous to speak for that unique philosopher, and attempt to outline the modifications he would introduce were he to walk on earth again and fly kites as of yore; for, with the exception of Jefferson, perhaps his was the most far-seeing and ingenious mind of a remarkable age. But the world moves; and in making kites, as well as in devising electrometers and apparatus for measuring the electricity of the air, great advances have been made. Franklin would enjoy repeating his kite experiment to-day, using modern apparatus. What changes and lines of investigation he would suggest are beyond conjecture.

A hundred and fifty years ago a ragged colonial regiment drew up before the home of its philosopher-colonel and fired an ill-timed salute in his honor. A fragile electrical instrument was shaken from a shelf and shattered. Franklin doubtless appreciated the salute and regretted the accident. In the course of his long life he received other salutes, as when the French Academy rose at his entrance; and he constructed and worked with other electrometers; but for us that first experience will always possess a peculiar interest. The kite and the electrometer betray the intention of the colonial scientist to explore the free air, and, reaching out from earth, study air electrification *in situ*. He made the beginning by identifying the lightning flash with the electricity developed by the frictional

machine of that time. A hundred patient philosophers have carried on the work, improving methods and apparatus, until to-day we stand upon the threshold of a great electrical survey of the atmosphere. It is no idle prophecy to say that the twentieth century will witness wonderful achievements in measuring the potential of the lightning flash, in demonstrating the nature of the aurora, and in utilizing the electrical energy of the cloud. The improved kite and air-runner will be the agency through which these results will be accomplished.

The famous kite experiment is described by Franklin in a letter dated October 19, 1752: "Make a small cross of light sticks of cedar, the arms so long as to reach to the four corners of a large, thin silk handkerchief when extended. Tie the corners of the handkerchief to the extremities of the cross, so you have the body of a kite which, being properly accommodated with a tail, loop, and string, will rise in the air like those made of paper, but being made of silk is better fitted to bear the wet and wind of a thunder-gust without tearing. To the top of the upright stick of the cross is to be fixed a very sharp-pointed wire rising a foot or more above the wood. To the end of the twine next the hand is to be tied a silk ribbon, and where the silk and twine join a key may be fastened. This kite is to be raised when a thunder-gust appears to be coming on, and the person who holds the string must stand within a door or window, or under some cover, so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window. As soon as the thunder-clouds come over the kite, the pointed wire will draw the electric fire from them, and the kite, with all the twine, will be electrified, and stand out every way and be attracted by an approaching finger. And when the rain has wet the kite and twine you will find the electric fire stream out plentifully from the key on the approach of your knuckle."

Now, how would we perform this experiment to-day and with what results? Having flown big kites during thunderstorms, it may perhaps be best to describe step by step two of these experiments, and then speak of what we know can be done, but as yet has not been done.

Our first repetition of Franklin's kite experiment was at Blue Hill Observatory, some ten miles southwest of Boston, one hundred and thirty-three years after its first trial. There were two large kites silk-covered and tin-foiled on the front face. These kites were of the ordinary hexagonal shape, for in 1885 Malay and Hargrave kites were all unknown to us. Fifteen hundred feet of strong hemp fish-line were wrapped loosely with uncovered copper wire of the smallest diameter suitable, and this was brought into a window on the east side of the observatory, through rubber tubing and blocks of paraffin. Pieces of thoroughly clean plate glass were also used. Materials capable of giving a high insulation were not so easily had then as now. We knew very little about mica; and quartz fibers and Mascart insulators could not be obtained in the United States. Our electrometer, however, was a great improvement upon any previous type, and far removed from the simple pith-ball device used by Franklin. Knowing that an electrified body free to move between two other electrified bodies will always move from the higher to the lower potential, Lord Kelvin devised an instrument consisting of four metallic sections, symmetrically grouped around a common center and inclosing a flat free-swinging piece of aluminum called a needle. The end of the kite wire is connected with the needle and the sections or quadrants are alternately connected and then electrified, one set with a high positive potential, say five hundred volts, and the other with a corresponding negative value, say five hundred volts lower than the ground.

Perhaps the most noteworthy result of these earlier experiments was the discovery (for such we think it was) that showery or thunder-storm weather was not the only condition giving marked electrical effects. The electrometer needle would be violently deflected and large sparks obtained at other times. Day after day as we flew the kite we found this high electrification of the air, and we had no trouble in getting sparks even when the sky was cloudless. One other discovery was made, and this would have delighted Franklin more than the other, for he was always most pleased when a practical application was in sight. Seated within the instrument room of the ob-

servatory, with his back to the open window through which came the kite wire carefully insulated, and the kite high in air, the observer closely watching the index of the electrometer could tell positively, and as quickly as one outside watching the kite, whether it rose or fell. When the kite rose, up went the voltage, and *vice versa*. In other words, the electric potential of the air increased with elevation. It must be confessed that the kites made to-day would have behaved better and flown with more steadiness than the one we used. It may have been the varying wind, or more likely wrong proportions in the kite and tail; but our old hexagonal kite would dive even when high in air. Once we kept the kite aloft from the forenoon until late at night, but that was something unusual.

Passing now over six years in which we had been busy measuring the electrification of the air under all conditions, and discovering, for example, that a snow-storm was almost identical with a thunder-storm in its tremendous electrical changes, we come to the year 1891, when we again flew kites for the purpose of electrically exploring the air. Our experiments at the top of the Washington Monument in 1885 and 1886 (especially those during severe thunder-storms, when we obtained potentials as high as three and four thousand volts just before the lightning), had given us an insight into the strains and stresses in the air, and taught us what to expect at such times. There was still little improvement in the kite, but much better electrical apparatus was at hand. It may seem ridiculous, but we hauled nearly a wagon-load of electrical apparatus to the summit of the hill, and found occasion to use all of it. Our insulators were delicate glass vessels, curiously shaped, containing sulphuric acid, and able to hold with little leakage the highest known potentials. Besides these fine Mascart insulators, we had hundreds of distilled-water batteries and two electrometers, one a Mascart quadrant, the other a large multiple quadrant. The chief aim that year was to secure by mechanical means (discarding the photographic and eye methods) a continuous record of the potential. When we can study the potential at any moment and still have a record of it, the relation of the electricity of the air to the pressure, temperature, and moisture

will be more easily investigated. Among our records that year there is one date, June 30, 1891, where a direct comparison of the electrification of the air fifteen or twenty feet from the ground and at a height of about five hundred feet is shown. In one, the potential was obtained by a water-dropper collector from a second-story window in the observatory, and in the other was obtained by means of the kite. It will be seen how much higher the kite values are, although the kite was a much slower accumulator of electricity. In the next year, 1892, the kite was flown several times during thunder-storms, but generally during afternoon storms; and in the lull preceding the wind rush the kite would fall. It was not until August 9th that we succeeded in going through a storm with the kite still flying. About 11 A.M. the kite was sent aloft, and it remained aloft until after 10 P.M. From the observatory one can see to the west fifty or more miles, and a thunder-storm came into view just about sunset. The kite was flying steadily, and whenever a finger was held near the kite-wire there was a perfect fusillade of sparks. As the darkness increased, the polished metallic and glass surfaces in the large electrometer reflected the sparks, now strong enough to jump across the air-gaps, and the incessant sizzling threatened to burn out the instrument. The vividness of the lightning in the west also made it plain that the storm was one of great violence, and as the observatory itself would be jeopardized, one of the four men present proposed to cut the wired string and let the kite go. But even that was easier said than done, for to touch the string was to receive a severe shock. It was necessary, however, to get out of the scrape, and one of the party took the kite-string and broke the connection with the electrometer and insulators. While he was in the act of doing this, the others, who by this time were outside the building, saw a flash of lightning to the west of the hill. The observer who was undoing the kite-wire did not see this flash. He saw a brilliant flare-up in the electrometer, and at the same instant felt a severe blow across both arms. Notwithstanding, he loosened the wire, and, dropping an end without, it took but a few moments to make it fast on the hillside some distance away from the observatory. There

it remained for the rest of the night. A 105-volt incandescent lamp was placed between the end of the kite-wire and a wire running to the ground. There was some light, but no incandescence of the filament. It was more in the nature of a creeping of the charge over the outer glass surface of the lamp. Stinging sparks were felt whenever the kite-wire was touched. The storm gradually passed over, the lightning being vivid and frequent in the west and north, and, as we learned next day, doing considerable damage. The nearest flash to the hill, however, as well as we could determine by the interval between thunder and flash, was 4,500 feet away, so that the discharge which the observer felt while loosening the wire must have been a sympathetic one. We obtained a photograph of the prime discharge, and very curiously this shows a remarkable change of direction.

In 1897, in some interesting experiments made on the roof of the Mills Building at San Francisco, it was noticed that the roof, which has a covering of bitumen, was a good insulator. Ordinarily one may touch the reel on which the kite-wire is wound without being shocked, but if a wire be connected with the ventilating pipes running to the ground there are small sparks. Introducing a condenser in the circuit, the intensity of the spark is increased. It only remains to construct an appropriate coil of the kite-wire and place within it another independent coil. In the outer coil a quick circuit-breaker may be placed, and theoretically at least we shall transform down the high potential and low amperage charge of the air to a current of less potential and greater amperage. This can be put to work and the long-delayed realization of Franklin's plan of harnessing the electricity of the air be consummated. It may not be a profitable investment from the commercial standpoint, but no one can say what this tapping of the aerial reservoir may lead to. Determining the nature and origin of the aurora will be as great a scientific achievement as utilizing the energy of Niagara Falls.

CHEMISTRY

The Great Problems of Chemistry

By ALFRED RUSSEL WALLACE

THE science of modern chemistry was created during the nineteenth century, but its phenomena and laws are so complex that it presents only a few of those great discoveries which are the starting-points for new developments, and which can at the same time be popularly described. The most important of all—that which constitutes the very foundation of chemistry as a science—is the law of chemical combination in multiple proportions, together with the atomic theory which serves to explain it.

The fact of chemical combination in definite proportions was suspected by some of the older chemists, but Dalton, in the early years of this century, was the first to establish it firmly as a general principle, and to explain it by means of a comparatively simply theory. To illustrate by examples, it is found that the two gases, nitrogen and oxygen, combine to form a variety of compounds, such as nitrous oxide or “laughing gas,” nitric oxide, and several others. Nitrous oxide, or in chemical language, nitrogen monoxide, consists of 28 parts by weight of nitrogen to 16 of oxygen, and all the other compounds of the same gases consist of two, three, four, or five times as much oxygen to the same quantity of nitrogen. Water consists of 16 parts of oxygen to 2 of hydrogen, and there is another compound in which 32 parts of oxygen combine with the same weight of hydrogen, forming hydrogen-dioxide or oxygenated water. This law applies to every chemical compound yet discovered, and as every element has a minimum propor-

tionate weight, which can combine with any other element, these are called the atomic or combining weights of the elements. As the weight of the hydrogen in all its combinations is much less than the weight of the element it combines with, this gas is taken as the unit of measurement of atomic weights. Nitrogen is thus found to have an atomic weight of 14, oxygen 16, and chlorine 35. These are all gases; but many solids have much lower atomic weights, carbon being 12, and the rare metal beryllium only 9. Of other metals, that of aluminium is 27, copper 63, iron 56, silver 107, tin 117, and gold 196. There is thus no constant relation between atomic weights and specific gravities. Tin is a little lighter than iron, but has nearly double its atomic weight; gold has a high atomic weight, but bismuth has a higher still, although only half its specific gravity.

These facts are elucidated, and to some extent explained, by the atomic theory of Dalton. He supposed each element to consist of atoms, an atom being the smallest portion that has the properties of the element, and the atom of each element has a different weight. Hence, when one element combines with another, the proportions must be either those represented by the atomic weights, or some multiple of those weights, since the atoms are assumed to be indivisible. This will be made clearer by another example. The atomic weights of nitrogen and oxygen are as 14 to 16, and these elements combine in five different proportions, as shown by the following, each letter representing an atom of the element of which it is the initial letter.

	Chemical Symbol.
N N O	= Nitrogen monoxide N_2O
N N O O	= Nitrogen dioxide N_2O_2
N N O O O	= Nitrogen trioxide N_2O_3
N N O O O O	= Nitrogen tetroxide N_2O_4
N N O O O O O	= Nitrogen pentoxide N_2O_5

The atomic or combining weights of all the elements having been carefully determined by numerous experiments, a beautiful system of chemical symbols has been formed which greatly facilitates the study of the innumerable complex substances that have to be investigated. Each element is indicated either

by one or two letters, being the initial letter, or some two characteristic letters, of its chemical name, so that nearly seventy elements are thus clearly defined. But these symbols represent not only the element, but a definite proportional weight—the atomic weight. Thus H means a unit weight of hydrogen; C means 12 times that weight of carbon; Fe (ferrum) means 56 times that weight of iron. Hence the symbol for any compound substance tells us in the most compact form possible, not only the elements of which it is composed, but the exact proportions in which these elements are combined. Thus C_2H_6O is the chemical symbol for pure alcohol, showing that it is a compound of two atoms of carbon, six of hydrogen, and one of oxygen. Looking now at a table of atomic weights, we find that this gives us 24 carbon, 6 hydrogen, and 16 oxygen in each 46 parts of alcohol. By means of these symbols and the accurate determination of atomic weights, all the complex combinations and decompositions that occur during the investigations of the chemist can be represented in a kind of chemical algebra, and the peculiar formulæ thus obtained often suggest further experiments leading to new discoveries.

Almost at the same time that Dalton was working at his atomic theory, Davy (afterward Sir Humphrey Davy) made the remarkable discovery of two new elements by decomposing soda and potash by means of an electric current, resulting in the production of the metals sodium and potassium. This placed in the hands of chemists a powerful agent which led to the discovery of other elements, though in this respect it has been surpassed by spectrum analysis, which is equally effective in the domains of chemistry and astronomy.

Among the more interesting discoveries of modern chemistry are the methods of liquefying the various gases, and even solidifying many of them; while by means of the intense heat of the electric furnace all the solid elements can be melted and many vaporized, leading to the conclusion that all matter can exist in the three states—solid, liquid, and gaseous—according to the degree of heat to which it is exposed.

The highly complex constitution of various organic products—albumin, fat, gums, resins, acids, oils, ethers, etc.—is the

subject of organic chemistry, the study of which has led to some of the most popularly interesting discoveries. Coal-tar has furnished us with a wonderful series of coloring matters, such as the aniline and other dyes, while from the same material are produced benzol, carbolic acid, naphtha, creosote, artificial quinine, and saccharine, a substitute for sugar. The new explosives, such as dynamite and nitro-glycerine, are produced from animal or vegetable fatty matters; while some of the greatest triumphs of the modern chemist are the artificial production of natural substances, which were long supposed to be due to organic processes alone. Such are the dye indigo, citric acid, urea, and some others.

The most recent great advance in the philosophy of chemistry is exhibited in the views of the Russian chemist, Mendeleef, as to the natural arrangement of the elements, with certain deductions from it. The whole of the best-known elements form eight groups, placed in vertical columns, depending on certain similarities in their powers of chemical combination. These are further arranged in twelve horizontal series, in which the atomic weights are most nearly alike, while increasing regularly from the first to the eighth group. In the table thus formed there are certain gaps in the regular order of increased atomic weights, as if some elements were wanting, while in other cases the place of an element due to its atomic weight did not accord with that dependent on its chemical properties. But the general symmetry of the whole arrangement was such that Mendeleef predicted the future discovery of elements to fill the gaps, and named the chemical and physical properties of these unknown elements. In a few years three new elements were discovered—gallium, scandium, and germanium—and they precisely filled up three of the gaps in the system. Further research as to the atomic weights of the elements that did not fit into the scheme showed that errors had been made, that of uranium being much too low, while in the cases of gold, tellurium, and titanium it was too great. The remarkable success of these predictions—a success always considered the best proof of the truth of a theory—renders it almost certain that the true relations of the elements have now been approximately

ascertained, while it strengthens the belief of those who think that what we term elements are not really so, but that their differences depend on special modes of aggregation of a few simple atoms, whose cohesion is so strong that we are not yet, and perhaps never shall be, able to overcome it.

It is therefore by no means impossible, perhaps not even improbable, that methods will be discovered of either breaking up some of the elements and producing new elements which are common to two or more of them, or of solving the problem which occupied the alchemists of the Middle Ages — the transmutation of some of the inferior metals into gold.

EDITOR'S NOTE. — It may perhaps be considered an axiom in science that once the human mind looks upon certain conditions as established and certain natural processes sufficiently uniform to consider them as laws, new discoveries may cause the revamping of theories or a recasting of what once was considered settled. In chemistry the discovery of radium and radio-activity has wrought a revolution in our fundamental ideas. Once the elements were considered ultimate and immutable, but Sir William Ramsay found that radium, unmistakably an element, on the basis of our established theory, constantly was changing into the element helium. Likewise it was found by Debierne that the element actinium was changing into helium. The development of this and other discoveries has led to the realization that so far as the radio-active elements are concerned, a continuous transmutation is in progress, and a fair assumption is that all elements are undergoing disintegration and that electricity, simply looked upon as a form of energy or motion, may be the ultimate primordial material of our universe. Thus we have the early theory of the alchemist that the baser element might be transmuted into a more valuable one rather more than suggested. Such processes, if they occur, seem far beyond human control, and for all practical purposes, the established idea of the elements can continue for years to come.

CHEMISTRY

Ancient and Mediæval Chemistry

By M. P. E. BERTHELOT

CHEMISTRY is a modern science, constituted hardly a century ago; but its theoretical problems were discussed and its practices put in operation during all the Middle Ages. The nations of antiquity were already acquainted with them, and their origin is lost in the night of primitive religions and prehistoric civilizations. I have described elsewhere the first rational attempts to explain the chemical transformations of matter, and purpose now to speak of the chemical industries of the ancient world, and their transmission to the Latins of the Middle Ages. The story is of interest as showing how the cultivation of the sciences has been perpetuated in the material line by the necessities of their adaptations, through the catastrophes of invasions and the ruin of civilization. Only the total extermination of populations, such as was at times practiced by the Mongols and the Tartars, could completely destroy this cultivation. But such horrors as those perpetrated by Tamerlane have been of rare occurrence.

From the most remote times man has applied chemical operations to his necessities, performing them for metallurgy, ceramics, dyeing, painting, the preservation of food, medicine, and the art of war. While gold and sometimes silver and copper existed in the native state, and required only mechanical preparation, lead, tin, iron, and often copper and silver, had to be extracted from their usual minerals by very complicated artifices. The production of alloys necessary for the fabrication of arms, money, and jewels is also an essentially chemical art.

The study of the alloys used in goldsmiths' work gave rise to the prejudices and frauds of alchemy, as is proved by the testimony of an Egyptian papyrus preserved in the Leyden Museum, and of the writings of the Grecian alchemists.

The art of preparing cement, pottery, and glass, likewise, depends on chemical operations. The workmen who dyed stuffs, clothing, and tapestries in purple or other colors, an industry practiced first in Egypt and Syria and then in all the Grecian, Roman, and Persian world, not to speak of the extreme East, employed highly developed chemical manipulations; and the cloths found on the mummies and in the sarcophagi attest their perfection. Pliny and Vitruvius describe in detail the production of colors, such as cinnabar or vermilion, minium, red chalk, indigo, black, green, and blue colors, vegetable as well as mineral, performed by painters. The chemistry of alimentation, fruitful in resources and in frauds, was next practiced. The art was known of accomplishing at will those delicate fermentations which produce bread, wine, and beer, and which modify a large number of foods; also of falsifying wine by the addition of plaster and other ingredients. The art of healing, seeking everywhere for resources against diseases, had learned to transform and fabricate a large number of mineral and vegetable products, such as sugar of poppy, extracts of nightshade, oxide of copper, verdigris, litharge, white lead, the sulphurets of arsenic and arsenious acid; remedies and poisons were composed at the same time, for different purposes, by doctors and magicians. The manufacture of arms and of inflammatory substances—petroleum, sulphur, resins, and bitumens—had already, anciently as well as in our own time, drawn upon the talents of inventors and given rise to formidable applications, especially in the arts of sieges and marine battles, previous to the invention of the Greek fire, which was in its turn the precursor of gunpowder and of our terrible explosive matters.

This rapid review shows how far advanced in the knowledge of chemical industries the Roman world was at the moment when it went to pieces under the blows of the barbarians. But the ruin of the ancient organization came about by degrees:

while high scientific study, hardly accessible to coarse minds, ceased to be encouraged, and was gradually abandoned; while the Greek philosophers, knocked about between the religious persecution of the Byzantine emperors and the indifferent disdain of the Persian sovereigns, no longer trained pupils; while the great names of Grecian physics, mathematics, and alchemy hardly passed the time of Justinian, it is still certain that the necessity of professions indispensable to human life, or sought out by sovereigns and priests, could maintain and did maintain effectively most of the chemical industries.

Proofs of various kinds can be brought up in support of these reasonings. Some are drawn from the examination of the monuments, arms, potters' and glass ware, cloths, gems and jewels, and art objects of every kind which have come down to us. Such examination furnishes, in fact, incontestable results, provided the dates of the objects are certain, and they have not suffered restoration. Respecting the date, we cannot exercise too much prudence and distrust, whether we are examining buildings or objects in museums. The accounts and descriptions by contemporary historians furnish other data, but less precise, for it is better to have the object in hand than the description. They have the advantage, however, of giving us indications independent of the ulterior progress of the industry. We have a still surer and more exact class of data than the chronicles in the technical treatises and works concerning arts and trades which have come down to us, whenever those treatises have an ascertained date, even were it only the date of their copies. This source of facts is already known as to antiquity. It is not wanting as to the Middle Ages, although it seems to have escaped till now the erudite persons who have written the history of science, and it permits us to reconstitute that under a new form and with a new precision. By the aid of those documents I shall attempt to show, concerning myself especially with chemical industries, what knowledge, practical or theoretical, subsisted after the fall of ancient civilization, and how the traditions of the shop maintained those industries, almost without new inventions, but at least at a certain level of perfection.

The history of physical science in antiquity is very imperfectly known to us. There existed then no methodical treatise for the purpose of teaching, such as we have in the principal civilized states. Hence, except as to the medical sciences, we have only insufficient notions respecting the processes employed in the arts and trades of the ancients. The experimental method of the moderns has associated those practices into a body of doctrines, and has shown close relations between them and the theories for which they served as basis and confirmation. This method was almost unknown to the ancients, and was, at best, only a general principle of scientific learning. Their industries had little connection with theories excepting in measures of length, surface, or volume, which were deduced immediately from geometry and in goldsmiths' receipts—the origin of the theories, partly real and partly imaginary, of alchemy.

It has even been asked whether industrial formulas were not formerly preserved by purely oral tradition and carefully held back for the initiated. Some scraps of the traditional lore may have been transcribed into the notes which have been used in the composition of Pliny's *Natural History* and the works of Vitruvius and Isidore de Seville, not without a considerable mixture of fables and errors. But a more thorough examination of the works that have come down to us from antiquity, a more attentive study of the manuscripts, at first neglected because they did not relate to literary or theological studies or to ordinary historical questions, permits the affirmation that they were not so. We are all the time discovering new and considerable documents which show that the processes of the ancient industrials were then, as now, inscribed in workmen's note-books or manuals intended for the use of the tradespeople, and that they were transmitted from hand to hand from the most remote times of ancient Egypt and Alexandrine Egypt, to those of the Roman Empire and the Middle Ages. The discovery of these note-books offers all the more interest because the use of the precious metals with civilized peoples goes back to the highest antiquity; the technic of the ancient goldsmiths and jewelers is not revealed to us all at once except

by the examination of the objects that have come down to us. The earliest precise and detailed texts describing their processes are contained in an Egyptian papyrus found at Thebes, and now in the museum at Leyden.

This papyrus is in the Greek language and dates from the third century of the Christian era. In my translation of it, comparing parts of it with phrases in the works of Pliny and Vitruvius on the same subjects and with Greek alchemistic works of the fourth and fifth centuries, I have reconstituted a whole science, ancient alchemy, till now misunderstood and uncomprehended, because it was founded on a mixture of real facts, profound views on the unity of matter, and chimerical religious fancies. These practices and theories had a still larger bearing than the working of metals. The industries of the precious metals were, in fact, associated at that epoch with those of the dyeing of cloths, the coloring of glasses, and the imitation of precious stones, all guided by the same tinctorial ideas and executed by the same operators.

Thus alchemy and the chimerical hope of making gold were derived from the goldsmiths' artifices for coloring metals. The pretended processes of transmutation which were current during the Middle Ages were in their origin only tricks for preparing alloys of inferior standard—that is, for imitating and falsifying the precious metals. But, by an almost invincible attraction the operators addicted to these practices did not hesitate to imagine that one could pass from the imitation of gold to its effective formation—especially if he had the aid of the supernatural powers, invoked by magical formulas.

At any rate, it was not known till now how these practices and theories passed from Egypt, where they were flourishing toward the end of the Roman Empire, into the West, where we find them in full development from the thirteenth and fourteenth centuries in the writings of the Latin alchemists and in the laboratories of the goldsmiths, dyers, and makers of colored glass. Their renaissance was generally attributed to translations of Arabian works made at that epoch. But, without assuming to deny the part played by the Arabian books in the renaissance of the arts and sciences in the West, in the period

of the Crusades, it is no less certain that a continuous tradition subsisted in the professional recollections of the arts and trades from the Roman Empire till the Carlovingian period, and later—a tradition of chemical manipulations and scientific and mystical ideas. In fact, in pursuing my studies of the history of science, I have met, in the examination of the Latin works of the Middle Ages, certain technical manuals which were related most directly with the metallurgical treatises of the Greco-Egyptian alchemists and goldsmiths. I purpose to demonstrate here this correlation, which nobody has till now pointed out.

It is known that the recipes of therapeutics and *materia medica* have been preserved in a parallel way by practice, which has never ceased, in the Receptaries and other Latin treatises; these treatises, translated from the Greek during the period of the Roman Empire, and compiled in the first and second centuries, passed from hand to hand, and were copied frequently during the earlier portions of the Middle Ages. The transmission of the military arts and of fire-producing formulas, particularly, was carried on from the Greeks and Romans through the barbarous ages. In short, the necessity of the applications has always caused the subsistence of a certain experimental tradition of the arts of ancient civilization.

The oldest known technical treatises in Latin of the Middle Ages on subjects in chemistry are the "Formulas for Dyeing" (*Compositiones ad tingendo*), of which we have a manuscript written toward the end of the eighth century, and the "Key to Painting" (*Mappæ clavicula*), the oldest manuscript of which is of the tenth century. The "Formulas for Dyeing" is not a methodical work, but a book of receipts and documents collected by a dyer for use in his art and intended to furnish him with working processes and information concerning the origin of his prime materials. It concerns such subjects as the coloring or dyeing of artificial stones for mosaic work; gliding and silvering and polishing them; making of colored glass in green, milky white, various shades of red, purple, yellow—the colors being both deep and superficial, and often brought out by the aid of simple varnishes; coloring of skins in purple, green, yellow, and various reds; dyeing of woods, bones, and horns;

notices of minerals, metals, and earths used in goldsmiths' work and painting. Curious ideas are set forth on the function of the sun and of heat, peculiar to certain warm earths in the production of minerals endowed with corresponding virtues; while a cold earth produces minerals of weak quality. This reminds us of the theories of Aristotle on dry exhalation as opposed to moist exhalation in the generation of minerals—theories that made an important figure in the Middle Ages. The author distinguishes a feminine and light lead mineral as against a masculine and heavy mineral; a distinction like that mentioned by Pliny between male and female antimony, the male and female blue of Theophrastus, and many others. Minerals were continually likened in the chemistry of the Middle Ages to living beings.

In this work we read, likewise, of articles developed in certain operations, such as the extraction of mercury, lead, the roasting of sulphur, preparations of white lead and vinegar, of verdigris with vinegar and copper—already described by Theophrastus and Dioscorides—of cadmies, impure oxides of lead and zinc, of burned copper (*æs ustum*), of litharge, of orpiment, of artificial cinnabar, etc. The writer mentions a few alloys, such as bronze, white copper, and gold-colored copper—a subject often treated of by the Greek alchemists, who passed from it to the idea of transmutation. The name of bronze (*brundisium*) appears for the first time. While its origin has been the subject of controversy among philologists, the accompanying facts given in the text show that bronze was in the beginning an alloy made at Brundisium for the manufacture of the mirrors of which Pliny speaks. The preparation of parchment and of varnish, the fabrication of vegetable colors for the use of painters and illuminators, and their employment on walls, wood, canvas, etc., in encaustic or with isinglass, are the subjects of separate articles.

A group of formulas for gilding follow: gilding of glass, wood, skins, clothing, lead, tin, and iron; and the preparation of golden wires, processes for writing in golden letters (chrysography) on parchment, paper, glass, or marble. Then come silver foil, tin foil, and processes for reducing gold and silver to

powder, in which mercury and verdigris were employed—the powder obtained by amalgamation being used in processes for silvering and gilding. The process has played its part in political economy; for it has been used to assist the passage of gold and silver from one country to another, in spite of the prohibition of the exportation of the precious metals.

The author goes on to say: "We have described everything relative to tinctures and decorations; we have spoken of the substances which are employed in them—stones, minerals, salts, and herbs; we have shown where they are found; whence are got resins, oleoresins, and earths; what are sulphur, black water, salt waters, glue, and all the products of wild and cultivated plants, domestic and marine; beeswax, axunge, all fresh and acid waters; among woods, the pine, fir, juniper, and cypress, . . . acorns and figs. Extracts are made of all these things with a water made of fermented urine and vinegar, mixed with rain-water."

These enumerations and descriptions mark the nature of the knowledge sought by the writer, and preserve the trace of ancient treatises on drugs and medicines, similar to those of Dioscorides, but more especially devoted to industry. Unfortunately, we have here hardly anything else than titles and summary indications, such as would figure in a dyer's scrap-book, placing, one after another, indications drawn from different authors. Many of the specific names found in the treatise are wanting in the most complete dictionaries. The terms salt, fresh, and acid waters, water formed of fermented urine and vinegar, deserve special notice because they point to the beginning of chemistry by moist processes. They figured in Pliny and the ancient authors, to the same purposes. The liquids are always natural ones or the results of the mixture of such, before or after spontaneous combustion. There is no mention of the active liquids obtained by distillation, which were called divine or sulphurous waters, and held an important place with the Greco-Egyptian chemists, and became the origin of our acids, alkalies, and other agents; they had not yet entered into industrial use, and are seldom met with previous to the fourteenth century.

The group of recipes transmitted by the formulas for dyeing, passed into a more extended collection called the "Key to Painting," of which exist a manuscript of the tenth century in the library of Schlestadt and one of the twelfth century, of which an edition was published in 1847 by Mr. Way. The former manuscript is free from all Arabian influence, which has caused the interpolation of five additional articles in the second one. The work contains a treatise on the precious metals comprising now a hundred articles—about half of the original work, the other half having been lost—and a treatise on recipes for dyeing, representing principally those in the Formulas; together with sixteen articles on military ballistics and fireworks, forming a special group; articles on the hydrostatic balance and the densities of the metals; and industrial and magic recipes, added at the end of the book.

The treatise on the precious metals is of great interest because of the striking analogies it presents with the Leyden Egyptian papyrus found at Thebes, and with other ancient works. Many of the recipes are literally translated from these ancient works; an identity proving indisputably the continuous preservation of alchemic practices, including transmutation, from Egypt down to the artisans of the Latin West. The theories proper, on the other hand, did not reappear in the West till toward the end of the twelfth century, after they had passed through the Syrians and the Arabs. But the knowledge of the processes themselves was never lost. This fact is demonstrated by the study of the alloys intended to imitate and falsify gold; for coloring (copper) gold-color; for fabricating gold; for making test gold; for rendering gold heavier; and for doubling gold. The recipes are filled with Greek words that betray their origin.

The object for the most part is simply to make base gold, as, for instance, by preparing an alloy of gold and silver, colored with copper. The goldsmith, however, tried to make this pass for pure gold. Then manufactures of complex alloys which were made to pass for pure gold were made easier by the intervention of mercury and sulphurets of arsenic, the use of which goes back to the earliest times of the Roman Empire. Thus

Pliny relates in a few lines an experiment performed by order of Caligula for fabricating gold with sulphuret of arsenic (or orpiment). There was thus a whole special chemistry, now abandoned, which was conspicuous in the practices and pretensions of the alchemists. A patent has been obtained in our own times for an alloy of copper and antimony, containing six hundredths of the latter metal, which presents most of the apparent properties of gold and is worked in the same manner. Alchemic gold belonged to a family of similar alloys. Those who made it fancied besides that some agents played the part of ferments to multiply gold and silver. Before deceiving other people they deluded themselves. Sometimes the artisan was satisfied to use a cement or superficial action, painting the surface of silver in gold or the surface of copper in silver, without modifying the metals in their thickness. This is what goldsmiths still call giving color. They would even do no more than apply to the surface of the metal a gold-colored varnish, prepared with the bile of animals or with certain resins, as is still done. From these colorings the operator, led by a mystic analogy, passed to the idea of transmutation, in the false Democritus and in the *Key to Painting*. The author of the last work concluded, for example, with the words, "You will thus obtain excellent gold and fit for the test." The author added, further, "Hide this sacred secret, which should be delivered to no one, nor to any prophet." The word prophet betrays the Egyptian origin of the recipe. It refers to the Egyptian priests, who, according to a passage in Clement of Alexandria on the Hermetic books that were borne with great pomp in the processions, were called prophets.

In further proof of the Greco-Egyptian origin of goldsmiths' recipes contained in the "*Key to Painting*," is the existence in the Latin collection of ten recipes—some of the elaborate ones—which are phrased in precisely the same terms in the Greek papyrus in Leyden; the former text being translated from the latter, even to the detail of certain technical expressions, which are still perpetuated in the goldsmiths' manuals of the present. This does not mean that the text transcribed in the "*Key to Painting*" was originally translated from the very papyrus that

we possess, which was not found till the nineteenth century at Thebes, Egypt; but the coincidence of the text proves that there existed books of secret goldsmiths' recipes transmitted from hand to hand of the tradesmen, which continued through the Middle Ages, and of which the Key is an example. It was firmly believed in the time of Diocletian that the Egyptians had the secret of enriching themselves by making gold and silver; and in consequence of this belief, after a revolt, the Emperor ordered all their books burned. Nevertheless, as we have seen, the formulas did not disappear.

The title of one of the recipes in the old table, "How to make unbreakable glass," deserves to be dwelt upon, on account of the legends and traditions that are associated with it, and which have been perpetuated down to our own time. Unbreakable glass appears to have been really discovered under Tiberius, and gave rise to a legend according to which its properties were amplified and it was made malleable. Tiberius, according to Pliny, caused the factory to be destroyed, for fear that the invention would diminish the value of gold and silver. "If it were known," wrote Petronius, "gold would become as cheap as mud." According to Dion Cassius, Tiberius slew the author. Petronius, who is repeated by other authors, says that he was decapitated, and adds that "if vessels of glass were not fragile they would be preferable to vessels of gold and silver."

These stories relate evidently to the same historical fact, reported by contemporaries, but disfigured by legend; the invention was probably suppressed for fear of its economical consequences. It is very curious to find it mentioned in the goldsmiths' recipes of the Middle Ages, as if the secret tradition had been preserved in the shops. Some of them claimed that glass could be made malleable and ductile and changed into a metal. A process for making glass that will not break has been discovered in our own times, and is announced unequivocally and in definite shape. In truth, malleable glass was not really in question; but even that is not a chimera. Industrial processes for beating and molding glass, based on the plasticity and malleability which it possesses at a temperature near fusion, have been described in late years. An article in the "Key to Paint-

ing" seems to point to a similar process. Real properties, perceived doubtless from antiquity and preserved as shop secrets, gave rise to the legend.

The collection bearing the name of Eraclius or Heraclius is in two parts, of different composition and date. The first part consists of two books in verse, having the character of the writing of the end of the Carlovingian epoch, or of the ninth and tenth centuries. It treats of vegetable colors, of gold leaf, of writing in letters of gold, of gilding, of painting on glass, and of the preparation of precious stones. All the recipes are of ancient origin, a little vague, and without novelty. A book in prose is more compact and precise. It was added later by a continuator, toward the twelfth century, for there is a discussion in it of the coloring of Cordovan leather, and cinnabar, which is red, is called in it azure—a translation of an Arabic word, frequent in the twelfth century, which has given rise to all sorts of misconceptions and confusion with our modern azure blue. It has the stories about malleable glass; and most of the subjects were already treated in the "Key to Painting."

The "Picture of Different Arts" of the monk Theophilus seems to be the work of an author who lived at the end of the eleventh century and beginning of the twelfth. It is more exact and detailed than the work of Eraclius, and is composed of two parts—the first devoted to painting, and the second concerning the making of objects required in worship and the construction of buildings devoted to it. It describes in detail the furnace for melting glass and the manufacture of glass, the making of painted glass and colored earthen vessels, the working of iron, the melting of gold and silver and the working of them, enamel, the fabrication of vessels used in worship—the chalice, monstrance, etc.—organs, bells, cymbals, etc. The facts are curious, for they show that the industry of glass and metals had finally concentrated around the religious edifices. But the chemical technique is the same as that of the other books, though savoring of more modern influences; it brings us directly to the thirteenth and fourteenth centuries, from which period monuments and writings multiply more rapidly down into modern times. The derivation of technical tradi-

tions from antiquity becomes less and less manifest as intermediaries multiply and the arts tend to assume an original character.

The facts I have presented deserve our attention as a whole, in view of the course and renaissance of scientific traditions. Sciences begin in fact with practice. The first object is to satisfy the necessities of life and the artistic wants that awaken early in civilizable races. But this same practice at once calls out more general ideas, which appeared first among mankind in a mystic form. With the Egyptians and Babylonians the same persons were at once the priests and the men of science. Thus the chemical industries were first exercised around the temples. The "Book of the Sanctuary," the "Book of Hermes," and the "Book of Kemi," all synonymous denominations with the Greco-Egyptian alchemists, represent the earliest manuals of those industries. It was the Greeks, as in all other scientific branches, who gave these treatises a revision freed from the old hieratic forms, and who tried to draw from them a rational theory, capable in its turn, by a similar application, of pushing the practice forward and of serving as a guide to it. But the chemical science of the Greco-Egyptians never rid itself of the errors relative to transmission—which were sustained by the theory of primal matter—or of the religious and magic formulas formerly associated in the East with every industrial operation. Yet when scientific study proper perished with Roman civilization in the West, the wants of life kept up the imperishable practice of the shops with the progress required in the time of the Greeks, and the chemical arts subsisted; while the theories, too subtle or too strong for the minds of the time, tended to disappear, or rather to return toward the ancient superstitions. In the "Key to Painting," as in the Egyptian papyrus and the texts of Zosimus, are mentions of prayers to be recited during the operations; and in this way alchemy remained intimately connected with magic in the Middle Ages as well as in antiquity.

During the Latin Middle Ages, toward the thirteenth century, when civilization began to revive, in the midst of a new organization, our races took up anew the taste for general ideas,

and these, in the sphere of chemistry, were sustained by practices, or rather they obtained their support in the permanent problems raised by them. Thus the alchemistic theories were suddenly revived, with new vigor and development, and their progressive evolution, while improving industry, gradually eliminated the superstitions of former times. Thus was finally constituted our modern chemistry, a rational science, established on purely experimental bases. The science was therefore born in its beginning of industrial practices; it kept course with their development during the reign of ancient civilization; when science went down with civilization practice survived and furnished science a solid ground on which it was able to achieve a new development when the times and the minds had become favorable. The historical connection of science and practice in the history of civilizations is therefore manifest. There is in it a general law of the development of the human mind.

CHEMISTRY

Chemical History of a Candle

(Selection)

By MICHAEL FARADAY

WHAT is all this process going on within us which we cannot do without, either day or night, which is so provided for by the Author of all things, that He has arranged that it shall be independent of all will? If we restrain our respiration, as we can to a certain extent, we should destroy ourselves. When we are asleep, the organs of respiration, and the parts that are associated with them, still go on with their action, so necessary is this process of respiration to us, this contact of air with the lungs. I must tell you, in the briefest possible manner, what this process is. We consume food: the food goes through that strange set of vessels and organs within us, and is brought into various parts of the system, into the digestive parts especially; and alternately the portion which is so changed is carried through our lungs by one set of vessels, while the air that we inhale and exhale is drawn into and thrown out of the lungs by another set of vessels, so that the air and the food come close together, separated only by an exceedingly thin surface: the air can thus act upon the blood by this process, producing precisely the same results in kind as we have seen in the case of the candle. The candle combines with parts of the air, forming carbonic acid, and evolves heat; so in the lungs there is this curious, wonderful change taking place. The air entering, combines with the carbon (not carbon in a free state, but, as in this case, placed ready for action at the moment), and makes carbonic acid, and is so thrown out into the atmos-

phere, and thus this singular result takes place: we may thus look upon the food as fuel. Let me take that piece of sugar, which will serve my purpose. It is a compound of carbon, hydrogen, and oxygen, similar to a candle, as containing the same elements, though not in the same proportion; the proportions in sugar being as shown in this table:

Carbon.....	72	} 99
Hydrogen.....	11	
Oxygen.....	88	

This is, indeed, a very curious thing, which you can well remember, for the oxygen and hydrogen are in exactly the proportions which form water, so that sugar may be said to be compounded of seventy-two parts of carbon and ninety-nine parts of water; and it is the carbon in the sugar that combines with the oxygen carried in by the air in the process of respiration, so making us like candles; producing these actions, warmth, and far more wonderful results besides, for the sustenance of the system, by a most beautiful and simple process. To make this still more striking, I will take a little sugar; or to hasten the experiment I will use some syrup, which contains about three-fourths sugar and a little water. If I put a little oil of vitriol on it, it takes away the water, and leaves the carbon in a black mass, and before long we shall have a solid mass of charcoal, all of which has come out of sugar. Sugar, as you know, is food, and here we have absolutely a solid lump of carbon where you would not have expected it. And if I make arrangements so as to oxidize the carbon of sugar, we shall have a much more striking result. Here is sugar, and I have here an oxidizer—a quicker one than the atmosphere: and so we shall oxidize this fuel by a process different from respiration in its form,—though not different in its kind. It is the combustion of the carbon by the contact of oxygen which the body has supplied to it. If I set this into action at once, you will see combustion produced. Just what occurs in my lungs—taking in oxygen from another source, namely, the atmosphere—takes place here by a more rapid process.

You will be astonished when I tell you what this curious play of carbon amounts to. A candle will burn some four, five, six, or seven hours. What a wonderful change of carbon must take place under these circumstances of combustion or respiration! A man in twenty-four hours converts as much as seven ounces of carbon into carbonic acid; a milch cow will convert seventy ounces, and a horse seventy-nine ounces, solely by the act of respiration. That is, the horse in twenty-four hours burns seventy-nine ounces of charcoal, or carbon, in his organs of respiration, to supply his natural warmth in that time. All the warm-blooded animals get their warmth in this way, by the conversion of carbon, not in a free state, but in a state of combination. And what an extraordinary notion this gives us of the alterations going on in our atmosphere. As much as 5,000,000 pounds, or five hundred and forty-eight tons, of carbonic acid is formed by respiration in London alone in twenty-four hours. And where does all this go? Up in the air. If the carbon had been like the lead which I showed you, or the iron, which in burning produces a solid substance, what would happen? Combustion could not go on. As charcoal burns it becomes a vapor, and passes off into the atmosphere, which is the great vehicle, the great carrier for conveying it away to other places. Then what becomes of it? Wonderful is it to find that the change produced by respiration, which seems so injurious to us (for we cannot breathe air twice over), is the very life and support of plants and vegetables that grow upon the surface of the earth. It is the same also under the surface, in the great bodies of water; for fishes and other animals respire upon the same principle, though not exactly by contact with the open air.

CHEMISTRY

Liquid Air

By IRA REMSEN *

WATER, the substance most familiar to us, is known in the liquid, in the solid, and in the gaseous state. Everybody knows that by heating the solid it passes into the liquid state, and that by heating the liquid it passes into the form of gas or vapor. So also everybody knows that when the vapor of water is cooled it is liquefied, and that by cooling liquid water sufficiently it becomes solid or turns to ice. In the same way many of the substances that are known to us as liquids, such as alcohol and ether, can be converted into the form of gas or vapor by heat. In fact, this is true of most liquids. The temperature at which a solid passes into the liquid state is called its melting point, and the temperature at which a liquid passes into the gaseous state is called its boiling point. The boiling point of water, for example, is 100° C. (212° F.) in the open air. But the boiling point varies with the pressure exerted upon the surface. The pressure that we ordinarily have to deal with is that of the atmosphere. If the pressure is increased the boiling point is raised, and if the pressure is decreased the boiling point is lowered. In dealing, then, with the conversion of a gas into a liquid, or that of a liquid into a gas, both the temperature and the pressure have to be considered.

Just as water is most familiar to us in the liquid form, so there are substances that are most familiar to us in the gaseous form. In fact, the only gaseous substances that can be said to

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be familiar to everybody are the gases contained in the air. The principal constituents of the air are nitrogen and oxygen, which form respectively about four-fifths and one-fifth of its bulk. Besides these gases, however, the air contains water vapor, carbonic-acid gas, ammonia, argon in small quantities, and many other substances in still smaller quantities. For the purposes of this article it is only necessary to have in mind the nitrogen, oxygen, water vapor, and carbonic acid. Of these, the water vapor is easily converted into liquid, as, for example, in the formation of rain, while the other constituents are liquefied with difficulty. The name "liquid air" is applied to the substance that is obtained by converting the air as a whole into a liquid; but in this process the water and the carbonic acid become solid and can be filtered from the liquid so that the latter consists almost wholly of oxygen and nitrogen. A few years ago this liquid was obtainable in only very small quantities. To-day it can be produced in any desired quantity, and at moderate cost, not only for the laboratory work of the physicist or chemist, but for industrial uses. It has come to be talked about in a familiar way, and many persons have had the privilege of seeing and feeling it, and of learning something about its wonderful properties. The object of this article is to explain the method employed in the production of liquid air, to give an account of some of its properties, and to indicate some of the uses to which it may possibly be put.

In the older text-books of physics and of chemistry certain gases were classed as "permanent," under the impression that these could not be liquefied, and this impression was based upon the fact that all efforts to liquefy them had failed. A brief account of these efforts will be helpful.

Among the so-called permanent gases was chlorine. An English chemist, Northmore, first succeeded, early in the last century, in liquefying chlorine. His work was, however, lost sight of, and in 1823 Faraday at the Royal Institution showed independently that this transformation of gaseous chlorine into the liquid can be effected comparatively easily. The method used by him is this: When chlorine gas is passed into cold water it forms with the water a solid product known as chlorine hydrate.

If kept well cooled this hydrate can be dried. If then its temperature is raised even to the ordinary temperature of the room, the solid hydrate is decomposed into liquid water and gaseous chlorine. Faraday put some of the solid hydrate into a stout glass tube sealed at one end and bent at the middle. The other end of the tube was then closed. The tube was then suspended so that the two ends were turned downward. On gently warming the end in which was the solid hydrate this was decomposed into chlorine and water. But the gas given off would under ordinary conditions have occupied a much larger space than the solid hydrate. Being prevented from expanding by the tube in which it was inclosed, it was under very considerable pressure. The end of the tube that was not warmed was cooled, and in this end, in consequence of the pressure and the comparatively low temperature, chlorine, which is gaseous under the ordinary pressure of the air, appeared as a liquid. The general method made use of by Faraday in this classical experiment is that which is always made use of for the purpose of liquefying gases, but for some gases pressure is very much higher and temperatures very much lower are required. Faraday himself succeeded in liquefying all the gases then known except oxygen, hydrogen, nitrogen, nitric oxide, and marsh gas. He subjected oxygen to a pressure of about one thousand pounds to the square inch, or nearly seventy atmospheres, but it showed no signs of liquefaction. Later experimenters increased the pressure to 4,000 pounds to the square inch, with no better results, so that it is not surprising that it came to be held that some gases are permanent.

Within comparatively recent years several gases have been liquefied on the large scale by means of pressure. These are ammonia, carbonic acid, nitrous oxide, and chlorine. Ammonia is used for producing low temperatures, as in breweries and in cold-storage plants and in the manufacture of ice; carbonic acid, for fire extinguishers and for charging beer with the gas; nitrous oxide, for producing anæsthesia; and chlorine in connection with several branches of chemical manufacture. The production of low temperatures by means of liquid ammonia and of liquid carbonic acid will be more fully dealt with further

on, when the principles involved will be briefly presented. It is to be borne in mind that these substances are liquefied by means of pressure alone, at temperatures that are easily reached, so that it appears that by mechanical pressure it is possible to produce low temperatures. In 1869 an important fact was discovered by Andrews. It was that for every gas there is a temperature above which it is impossible to liquefy it by pressure. Thus, if chlorine is at any temperature above 146°C. (294°F.) it cannot be liquefied. This temperature is called the "critical temperature" of chlorine. The pressure to which the gas must be subjected at the "critical temperature" in order that the gas may be liquefied is called the "critical pressure." In the case of chlorine this is 93.5 atmospheres. Now the critical temperature of the gases that were called permanent gases are very low—lower than could be reached by the means at the command of earlier experimenters. The critical temperature of oxygen, for example, is -118.8°C. (-182°F.), while that of nitrogen is -146°C. (-230°F.). The critical pressures are 50.8 and 35 atmospheres respectively. As there is no difficulty in obtaining these pressures, the problem of liquefying oxygen and nitrogen and air resolves itself into finding a method of producing temperatures below the critical temperatures of these gases.

It is well known that a temperature somewhat below the freezing point of water can be produced artificially by mixing ice and salt. The ordinary ice-cream freezer is a familiar application of this method of producing cold. Other freezing mixtures that are sometimes used consist of calcium chloride and snow, that gives the temperature -48°C. (-54.4°F.), and solid carbonic acid and ether, that is capable of lowering the temperature to -100°C. (-148°F.). But even with the latter mixture it is not possible to reach the critical temperature of oxygen or that of nitrogen. How, then, is it possible to reach these extremely low temperatures?

In order to answer this question it will be necessary to take into consideration certain temperature changes that are observed when solids are melted and liquids are boiled, as well as when gases are liquefied and liquids are frozen. When heat is

applied to a mass of ice at its melting point it melts and forms a mass of water having the same temperature. Heat disappears in the operation. It is stored up in the water. This disappearance of heat that accompanies the melting of ice can be shown in a very striking way by mixing a certain weight of ice with the same weight of water that has been heated to 80°C . (176°F). The ice will melt and all the water obtained will be found to have the temperature of the melting ice—that is, 0°C . (32°F). The water of 80°C . is thus cooled down to 0° by the melting of the ice. Again, when heat is applied to water its temperature rises until the boiling point is reached. Then it is converted into vapor, but this vapor has the temperature of the boiling water. During the process of boiling there is no rise in the temperature of the water or of the vapor. Heat disappears, therefore, or is used up in the process of vaporization. Similar phenomena are observed whenever a solid is melted or a liquid is boiled. When, however, a gas is liquefied it gives up again the heat that is absorbed by it when it is formed from a liquid; and so also when a liquid solidifies it gives up the heat it absorbs when it is formed from a solid.

But it is not necessary that a gas should be converted into a liquid in order that it should give up heat. Whenever it is compressed it becomes warmer. Some of the heat stored up in it is, as it were, squeezed out of it. Conversely, whenever a gas expands, it takes up heat and, of course, surrounding objects from which the heat is taken become colder. Now, it is a comparatively simple matter to compress air. Every wheelman knows that, and he also knows that the process causes a rise in temperature; at least he knows it if he uses a small hand pump. With large pumps run by steam any desired pressure can be reached. This is simply a question of securing the proper engines, and vessels sufficiently strong to stand the pressure. It has already been pointed out that several gases are now liquefied on the large scale by means of pressure. It is to be noted that low temperatures can be produced by converting certain gases, such as ammonia and carbonic acid, into liquids, and by compressing certain gases, as, for example, air. When liquefied gases are used it is only necessary to allow

them to pass rapidly into the gaseous state, when more or less heat is absorbed. This is the basis for the use of liquid ammonia in the manufacture of ice. A vessel containing the liquid ammonia is placed in another containing water. The inner vessel being opened, the liquid ammonia is rapidly converted into the gas; heat is absorbed from the water; it freezes. When a vessel containing liquid carbonic acid is opened so that the gas that is formed escapes through a small valve, so much heat is absorbed that a part of the liquid carbonic acid is itself frozen. In this case the substance is present in all three states of aggregation—the solid, the liquid, and the gaseous. The use of a mixture of ether and solid carbonic acid as a freezing mixture has already been referred to. Its value depends, of course, principally upon the fact that solid carbonic acid is liquefied, and the liquid then converted into gas, both of which operations involve absorption of heat.

We are now prepared to understand the important experiments of Cailletet and of Pictet, the results of which were published in 1877. It should be said that they worked independently of each other—Cailletet in Paris and Pictet in Geneva. Pictet liquefied carbonic acid and sulphur dioxide by pressure. The liquid carbonic acid was passed through a tube that was surrounded by liquid sulphur dioxide boiling in a partial vacuum. The liquid carbonic acid thus cooled was then boiled under diminished pressure in a jacket surrounding a tube in which the gas to be liquefied was contained under high pressure. When this gas was allowed to escape from a small opening its temperature was so reduced by the expansion that a part of it was liquefied in the tube and passed off as a liquid. Cailletet worked in essentially the same way, but on a smaller scale. Neither of these experimenters liquefied oxygen or nitrogen on the large scale, but they pointed out the way that must be followed in order that success may be attained. They destroyed the belief in "permanent" gases.

Later experimenters in this field were Wroblewski, Olszewski, and Dewar, who were interested mainly in the purely scientific side of the problem, while Linde in Germany, Hampson in England, and Tripler in the United States had their

minds on the practical side. Notwithstanding the low temperatures involved in the experiments, a number of heated discussions were carried on in the scientific journals touching the question of priority. To the unprejudiced observer it appears that all of those named above are entitled to credit. They have all helped the cause along, but just how to apportion the credit no one knows. In a general way, however, some of the results obtained by each in turn should be given. Wroblewski and Olszewski have carried on the work begun by Cailletet and Pictet, and have produced lower temperatures.

In the latest form of apparatus used by Olszewski, liquid ethylene is used as the cooling agent. Its boiling point is -102°C. (-151.6°F.). By causing it to boil rapidly under diminished pressure a temperature below the critical temperature of oxygen can be reached. As early as 1891, Olszewski obtained as much as two hundred cubic centimeters of liquid air by this method. Dewar has also made use of liquid ethylene. This was passed through a spiral copper tube surrounded by solid carbonic acid and ether. It was then passed into a cylinder surrounded by another cylinder containing solid carbonic acid and ether. A spiral copper tube, which runs through the outer cylinder and also through the inner cylinder in which the ethylene was boiling under diminished pressure, carried the air. This was liquefied and then collected in a vacuum vessel below. Later he found that air can be liquefied by using liquid carbonic acid alone as the cooling agent. As he remarks: "With this simple machine, one hundred cubic centimeters of liquid oxygen can readily be obtained, the cooling agent being carbon dioxide, at the temperature of -79° . If liquid air has to be made by this apparatus, then the carbonic acid must be kept under exhaustion of about one inch of mercury pressure, so as to begin with a temperature of -115° ."

The introduction of the vacuum vessel by Dewar has been of great service in all the work on liquefied gases. A vacuum vessel is a double-walled glass vessel. The space between the inner and outer walls of the vessel is exhausted by means of an air pump before it is closed. The vessel is therefore surrounded by a vacuum. As heat is not conducted by a

vacuum, it is possible to keep specimens of liquefied gases in such vessels for a surprisingly long time. Heat enough cannot pass through the vacuum to vaporize the liquid rapidly. The most common form of these vessels is that of a globe. Such a vessel is known as a Dewar globe or bulb.

It has been found that liquid air can be kept very well by putting it in a tin or galvanized iron vessel, which in turn is placed in a larger one, and then filling the space between the two with felt. Under these conditions vaporization takes place quite slowly, and it is possible to transport the liquid comparatively long distances. In one case with which the writer is familiar two cans of liquid air were taken from a New York laboratory in the morning, delivered at the Johns Hopkins University, in Baltimore, in the afternoon, and used to illustrate a lecture in the evening. After the lecture there was enough left for certain experiments that were carried on during the rest of the night.

Tripler, Linde, and Hampson all succeeded in devising various forms of apparatus by means of which air can be liquefied without the aid of other cooling agents than the expanding air. In principle the methods employed by these three workers were essentially the same. From small laboratory installations capable of yielding but half a pint or so of liquid air and that at an extraordinarily high cost, plants have been developed on a practical and commercial basis, capable of industrial application and a large output. In substance the method of operation is essentially as follows: The first consideration is a source of power to work the compression pumps. Air is taken from above the roof of the laboratory. In the first pump it is compressed to sixty-five pounds to the square inch. It, of course, becomes heated as it is compressed. In order to cool it down again it is passed through a coil connecting the first and second pumps, which is surrounded by water of the ordinary temperature. This compressed and cooled air is then further compressed in the second pump to four hundred pounds to the square inch. Again it is cooled in the same way as before by means of water which circulates around a coil connecting the second and third pumps. Once

more the air is compressed, this time in the third pump, in which it is subjected to a pressure of 2,000 to 2,500 pounds to the square inch; and then this compressed air is brought down to the ordinary temperature in a cooler consisting of a coil similar to those connecting the pumps. The air under this great pressure is now passed through a purifier where it is freed from particles of dust and to a great extent from moisture. From the purifier the air passes into an inner bent tube, about thirty feet in length, at the end of which, the critical point of the apparatus, is situated a needle valve from which the air is allowed to escape. It, of course, expands enormously, and is correspondingly cooled. This very cold air passes into the space between the inner and outer tubes, and finally escapes at a vent at the other end of the bent tube. The result of this is that the compressed air in the inner tube is soon cooled down so far that a considerable part of the air that escapes at the needle valve appears in the liquid form. This collects in the lower part of the jacket, and on opening the stopcock underneath the liquid escapes in a stream the size of one's finger.

In a low temperature laboratory liquid air is collected in the cans already referred to. Although for the reasons mentioned the evaporation of the liquid is comparatively slow, it is constantly going on, and as the gas formed occupies a very much larger volume under the pressure of the atmosphere than the liquid from which it is formed, it is necessary to leave the cans loosely covered. Otherwise the pressure would increase to such an extent as to burst any but the strongest vessels. One cubic foot of liquid air gives at atmospheric pressure eight hundred cubic feet of gaseous air.

Liquid air obtained as described is a turbid, colorless liquid. The turbidity is due to the presence of solid water and solid carbonic acid. By passing the liquid through a paper filter the solids are removed, and transparent liquid is thus obtained. This, as already stated, consists mostly of nitrogen and oxygen in the proportion of about four-fifths of the former to one-fifth of the latter. Though it should not be forgotten that this liquid contains argon in small quantity, besides three or four other elementary substances in still smaller quantities, as has been

shown by Professor Ramsay, we may disregard everything except the nitrogen and oxygen. Liquid air is a *mixture* of these two substances. They are not chemically combined as hydrogen and oxygen are, for example, in water. This mixture boils at -191°C (-312°F .), which is the temperature of the liquid as it is in the cans. As the nitrogen boils at a lower temperature (-194°C . or 318°F .) than oxygen (-183°C . or 297°F .), more nitrogen is converted into gas in a given time than oxygen, and after a time the liquid that is left is much richer in oxygen than ordinary air. When liquid air is poured upon water, it, being a little lighter than the water, floats, not quietly, to be sure, but in a very troubled way. Soon, however, the liquid sinks to the bottom because the nitrogen, which is the lighter constituent, passes into the gaseous state, and the liquid oxygen which is left is a little heavier than water. The experiment is a very beautiful one. A scientific poet could alone do justice to it. The beauty is enhanced by the fact that while liquid air is colorless, or practically so, liquid oxygen is distinctly blue.

Although liquid air has the temperature -191°C . (-312°F .), one can without danger pass the hand through it rapidly. The sensation is a new one, but it is evanescent. Very serious results would follow if the hand were allowed to remain in the liquid even for a short time. The tissues would be killed. So also, it is possible to pass the hand rapidly through molten lead without injury. In the latter case the moisture on the hand is converted into vapor which forms a protecting cushion between the hand and the hot liquid; while, in the former case, the heat of the hand converts the liquid air immediately surrounding it into gas which prevents the liquid from coming in contact with the hand.

When the liquid is poured out of a vessel in the air it is rapidly converted into gas. The great lowering in the temperature causes a condensation of the moisture of the air in the form of a cloud. The same thing is seen when the cover is removed from a can containing the liquid. Of course, this liquid does not wet things as water does. When, however, at a public demonstration, the lecturer deliberately pours a dipperful

of the liquid upon a priceless Worth gown, he may expect to hear expressions of horror from the owner. This experiment passed off most successfully. Every trace of the liquid air was converted into invisible gases before the fleeting agony of the sympathetic audience had passed away.

The effects of very low temperature upon a number of substances have been studied, and some of them can easily be shown. Paraffin, resin, and rubber immersed in liquid air soon become very brittle, and the color of the resin is completely changed. A beefsteak or an onion also becomes brittle, and can be broken into small fragments by the blow of a hammer. A similar effect is produced in the case of some metals. Tin and iron, for example, become brittle, and the tenacity of the iron is greatly increased. A copper wire, however, retains its flexibility. At low temperatures the electric conductivity of all metals is increased. In general, the lower the temperature the greater the conductivity. If a copper wire could by any means be kept cold enough, electrical energy could be transmitted by it with but little loss—perhaps none. Mercury is easily frozen by surrounding it with liquid air, and the solid thus formed is very hard, though if it is cooled down sufficiently it becomes brittle.

Alcohol can be frozen without difficulty by means of liquid air. By the aid of the lowest temperatures hitherto attainable it has only been possible to convert alcohol into a pasty mass. The frozen alcohol is as hard as ice. When alcohol is dropped into liquid air the drops retain the globular form. When taken out on a platinum loop the flame of a Bunsen burner does not set fire to it.

Phosphorescence is greatly increased by cooling substances down to the temperature of liquid air. This has been shown by means of water, milk, paper, eggs, and feathers. An egg and a feather could be distinctly seen in a dark room.

Scarlet iodide of mercury is converted into the yellow variety when it is subjected to the temperature of liquid air. Some other colors are changed under the same circumstances, but not enough is known of this subject to warrant a general statement.

Attention has already been called to the fact that liquid air loses its nitrogen more rapidly than it does its oxygen, and that, after a time, the residue contains a large proportion of oxygen. As combustion is combination with oxygen, combustion or burning takes place more readily in contact with this liquid oxygen than it does in the air. If a lighted match is attached to the end of a steel watch-spring, and this then plunged beneath the surface of liquid air, the spring will soon take fire and burn brilliantly, the sparks flying off for some distance in beautiful coruscations. Hair felt, which does not burn in the air, burns in a flash when soaked with liquid air. Finally, when liquid air is confined in any vessel not capable of sustaining an enormous pressure, say about 10,000 pounds to the square inch, the vaporization goes on until the vessel bursts or the stopper is forced out. It might therefore be used as an explosive without any addition, but its manipulation is not altogether simple.

Now for the inevitable question: Of what use is liquid air likely to be? This is a perfectly proper question, and yet if scientific workers always stopped to ask it and would not work unless they could find a favorable answer, progress would, to say the least, be much slower than it is. Most great practical discoveries have necessarily passed through the plaything stage. Some of the most important discoveries have not even furnished playthings, and have found no practical applications as this expression is commonly understood. But the production of liquid air, while furnishing mankind with a beautiful and instructive plaything, seems likely to find practical applications. We may look for these in four directions, to each of which a short paragraph may be devoted:

First, as a cooling agent. Low temperature is marketable. To be sure, the demand for the extremely low temperature that can be produced by liquid air does not exist to-day, but this concentrated low temperature can be diluted to suit conditions. The only question to be answered in this connection is then, What is the cost of cold produced by liquid air? It is impossible for any one to answer this question at all satisfactorily at present. It can only be said that this is what experimenters

are trying to find out. It appears, however, that they are on the way to cheap liquid air, and that as the processes are improved the price will become lower and lower.

Second, for the construction of motors. There is no doubt that liquid air with its enormous power of expansion can be used as a source of motive power just as compressed air is. In the case of steam it is necessary to heat the water in order to convert it into steam, and to heat the steam to give it the power of expansion. The cost is, in the first instance, that of the fuel. Given a certain amount of heat, and a certain amount of work is obtained. If liquid air is used, the problem is much the same. Engines must be run in order to compress the air which is to be liquefied. Every gallon of liquid air has been produced at the expense of work of some kind. Now, the question arises at once, What proportion of the work that was put in that gallon of liquid air in the course of its production can be got out of it again? It is certain that all of it cannot be got out unless all that we have ever learned about such matters goes for nothing. In dealing with the problem of the application of liquid air as a source of motive power we are therefore doubly handicapped. In the first place, we do not know the cost of the liquid when produced on the large scale; and, in the second place, we do not know the probable efficiency of a liquid-air motor. Leaving out of consideration the question of cost, it may be pointed out that liquid-air engines would have the advantage of compactness, though they would necessarily be heavy, as they would have to be strong enough to stand the great pressure to which they would be subjected.

The third application of liquid air that has been suggested is in the preparation of an explosive. In fact, an explosive has been made and used for some time in which liquid air is one of the constituents. When the liquid from which a part of the nitrogen has boiled off is mixed with powdered charcoal, the mixture burns with great rapidity and great explosive force. Of course, this explosive must be made at or near the place where it is used. It is claimed that the results were satisfactory. The chief advantage of the explosive is its cheapness, and the fact that it soon loses its power of exploding.

Finally, the fourth application of liquid air is for the purpose of getting oxygen from the air. This can be accomplished by chemical means, but the chemical method is somewhat expensive. Oxygen has commercial value, and cheap oxygen would be a decided advantage in a number of branches of industry. It will be observed that it is the liquid oxygen that makes possible the preparation of the explosive described in the last paragraph. Oxygen, as such, in the form of gas is of value in Deacon's process for the manufacture of chlorine. In this process air and hydrochloric acid are caused to act upon each other so as to form water and chlorine. The nitrogen takes no part in the act, and it would be an advantage if it could be left out. It is only the oxygen that is wanted. There are many other possible uses for oxygen either in the liquid or in the gaseous form, but these need no mention here.

In conclusion it may safely be said that it is highly probable that liquid air will be found to be a useful substance, but it is impossible at present to speak with any confidence of the particular uses that will be made of it. As work with it is being carried on in at least three countries, we may confidently expect important developments in the near future.

EDITOR'S NOTE

The ability to produce liquid air in large quantities has had a most important bearing and effect on modern chemical and physical investigation. This achievement so interestingly and authoritatively described by President Remsen by no means marked the end of low temperature experimentation and accomplishment. With large supplies of liquid air available it was possible straightway to proceed to the liquefaction of those gases that hitherto had resisted all attempts in this direction. In the case of hydrogen such an achievement was hardly dreamed of by many of the older chemists, but when at the very outset the gas could be reduced to -190° centigrade an important start was made. The hydrogen so cooled was compressed to a pressure of about 200 atmospheres and then suddenly expanded in a regenerative coil, the resulting fall in temperature being sufficient to cause the gas issuing

from an orifice to contain drops of liquid. This rightly was assumed to be hydrogen in a liquid condition, and it was able to freeze liquid air and oxygen into hard white solids.

This happened in 1896, and the master investigator responsible for the brilliant performance was Professor James Dewar of England, who continued his work with improved apparatus so that by May, 1898, he was able to collect the liquid hydrogen, and by the following year the regular liquefaction of the gas could be undertaken. The liquid hydrogen had a temperature of -253° centigrade, but it was by no means the end of low temperature investigations. On July 10, 1908, helium, that rare gas detected in the distant stars by the spectroscope and then realized in the chemical laboratory by Sir William Ramsay, was liquefied by Dr. Kammerlingh-Onnes and its boiling point determined as 4° absolute, or -269° centigrade, while its temperature of solidification was estimated at 2° absolute.

It is also of interest to consider the industrial applications of liquid air suggested by Professor Remsen. The more sanguine hopes in this direction have not been realized, and those of the inventor Tripler were somewhat rudely shattered. Nevertheless, oxygen, which plays a very important part in chemical and industrial applications, such as for bleaching, autogeneous welding, metal cutting, etc., is obtained economically by the liquefaction of air. By a process of fractional distillation, somewhat similar to the Coffey still, the essential constituents, oxygen and nitrogen are separated, these gases boiling at -182.5° centigrade and -193.5° centigrade respectively. But all things considered, liquid air and liquid hydrogen as yet do not figure extensively in industrial work. To produce extremely low temperatures, paradoxical as it may seem, requires considerable expenditure of heat, and this obviously involves expense and naturally acts against the use of liquid air as a source of power as Professor Remsen has indicated. The temperatures of the liquid gases are too low for most needs, and those of ordinary methods of refrigeration suffice. Nevertheless the production of low temperatures is one of the greatest triumphs of modern science.

CHEMISTRY

The Potter's Art

By MARTHA WASHINGTON LEVY

THE progressive steps in the development of almost every art may be traced by examining the art as practiced by peoples of different stages of culture. With pottery, however, this is difficult, since there is only very meager information relating to it among uncivilized peoples, and few facts are recorded concerning the materials used and the methods followed in its production.

Since the art was intimately connected with the securing and preparing of food, it belonged, the world over, among savage tribes of a certain state of culture, to women.

It is probable that the first fire kindled on clay soil baked the clay and suggested to the builder of the fire the possibility of converting a soft and easily molded substance into a hard and permanent article of use. But who the first potter was, or where he worked, is unknown.

Like all arts, pottery was probably the result of a long development. But, after taking root, it flourished in proportion to the advance in culture of the people itself, so that to-day it exists in all stages of development, from the coarse ware of the savage to the fine porcelain of Sèvres.

The earliest examples of pottery belong to the Stone Age and bear all the characteristics of a primitive period. The material of which they are composed is coarse, while the objects themselves, made by hand without the potter's wheel, are crude in form and seem to have been imperfectly hardened in an open fire. The jars are frequently cylindrical in form—though

some are found that are rounded at the base and without feet. Ornamentation is confined to simple, incised lines produced by the impression of the finger-nail, or by a cord wound around the moist clay. Most of the urns of this period are sun-baked.

In the Bronze Age, while most of the pottery was still made by hand, it was wrought more skillfully, and in some instances shows marks of the potter's wheel. The forms, too, were more varied, and circles and figures cut in bronze were introduced as ornaments.

Egypt furnishes the earliest examples of pottery of a more advanced period, the oldest being the sun-dried bricks of which some of the pyramids are made. These occur in the pyramid of Sakkara, dating from the reign of Ouennephe, about 5000 B.C.

That they had the potter's wheel from an early period is shown in the painting on the wall of one of the tombs at Beni-Hassan, dating not far from the pyramid of Shoo-fou. From this it is evident that the art of forming circular objects has hardly been improved in 4000 years: then, as now, the lump of clay was thrown on the wheel to be shaped by the hands or fingers.

The Egyptians produced two varieties of pottery. The first—the ordinary, soft pottery—was used largely for vases, which were made into a variety of forms, and employed chiefly for domestic purposes or cinerary urns. But their highest art was displayed in the use of the enameled pottery, which they were the first to produce. This was usually employed in smaller articles and for inlaying in ornamental work.

From Egypt, the art is supposed to have passed to Nineveh and Babylon, where it was applied to the building of great walls of enameled brick. These colored bricks were formed in a wooden or terra-cotta mold, and many of them were impressed, while still soft, with elaborate cuneiform characters, serving thus to record the victories of the kings.

The finest objects in rude clay were produced by the ancient Greeks, whose most primitive productions, though dating from almost the heroic age, reveal a remarkable power of invention. Most of the vases were made of a fine, sun-dried clay, decorated

with black and coated with glaze. Though some were made by hand, the potter's wheel was used at an early date.

At first no effort at pictorial ornamentation was made, the only attempt at decoration being to cover the clay with interlacing lines. Later, birds, animals, and finally the human figure were introduced.

In Rome, pottery was extensively produced, and consisted largely of tiles, bowls, cinerary urns, and low boat-shaped lamps. The latter, though beautifully embossed, were made of coarse clay which was pressed, while soft, into molds. Later the Romans adopted a black, glazed surface, but in this never attained the perfection achieved by the Greeks. The best-known Roman pottery was the so-called Samian ware, bright red in color and molded in relief on the exterior.

MODERN POTTERY.

The process by which the present-day pottery is manufactured may be interesting to the reader. The rude clay is ground in a circular pan—the bottom of which is covered with a hard stone—and, after having been run into a large vat, is passed through several sieves of varying fineness. It is then ready to have the moisture eliminated, and for this purpose is pumped under high pressure into clay presses. Finally, after having been cut off into blocks, the clay is ready for use.

In studying the process by which the clay is converted into the various articles with which we are familiar, we visit first the thrower, who, after throwing a ball of clay on the wheel while it is revolving, seizes it and, by manipulation alone, contorts the clay until it has assumed the shape he requires. The wheel itself, while sometimes worked by steam power, can still be seen operated by hand labor as practiced by the potters of antiquity.

After being allowed to dry to a certain consistency, the article formed by the thrower is placed on a circular piece of wood, where all superfluous clay is removed, and it is thus given the proper shape and finish. When handles or spouts are required, they are made in molds and attached to the

articles with water. Flat articles such as plates, and hollow-ware such as soup tureens, are produced by beating out the clay on a suitable bat, smoothing its surface, and then pressing it into plaster of Paris molds. When the clay hardens, it is easily removed, and when quite dry is ready for the oven.

Another mode of producing articles of pottery is by casting. In this case, the plaster molds are filled, not with clay, but with the material, in a "slip" or liquid state. Owing to the suction of the plaster, a coating of clay adheres to the inner surface, and this is filled up until the desired thickness is obtained, when the surplus part is returned to the tub. Many useful articles such as cups, jugs, etc., are produced in this way.

Pottery ware in both the clay and biscuit state has to be fired in "saggars" or pans made of fire-clay. For china firing the ware is embedded in fine-ground flint, but earthenware is placed in clean sand, which prevents the articles from fusing together under the intense heat to which they are subjected.

The biscuit oven, which is the oven in which the ware receives its first fire, is cylindrical in form, with walls made of the hardest fire-brick, built fully two feet thick, and pierced at regular intervals by fire-places which open into the interior. The floor of the kiln is hollow, and over an opening in the center is a column of rings which carry the flame up the center, so that the whole oven is filled with flame.

After the saggars have been carried to the ovens, where they are piled up in tall columns until the entire space is filled, the doorway is bricked up and plastered over, and it is now ready to fire. Meanwhile, a pile of coals has been ignited outside, and the fire is started at all the fire-holes simultaneously.

When the ware is drawn from the oven it is taken to the warehouse, where it is carefully examined to discover any defects that have developed in firing, the defective pieces being rejected, while the others are stored ready for decoration.

DECORATIONS

Printing is one of the most popular modes for decorating pottery. The patterns are engraved upon suitably prepared



A GRECIAN POTTER
From a Painting by Paul Thumann.

copper, which the workman, when about to take off a print, places upon a hot stove and covers with a thick dab of color: this he works into every part of the pattern,* removes the surplus, and leaves the color only in the incised lines in the copper. He then saturates a piece of prepared tissue-paper with a solution of soft soap and water, places it upon the copper which has been removed quite warm to the press, and after the roller of this has revolved upon it, the engraving is again placed on the stove and the impression removed from the copper. The surplus paper having been cut away, the impression is rubbed upon the piece of ware under great pressure. The paper is then washed away without interfering with the print, and the ware is taken to the "hardening-on" kiln, where it is fired for about nine hours, in order that the thick oil may be burned out of the color, and the ware be thus made ready to receive the glaze.

The materials forming the glaze are fired in a special kiln and afterward mixed with other materials which are ground in water in the mill for about a week. After having been dipped into this glaze, which spreads itself as a thin glassy coating over the whole surface of the article, the latter is taken to the glazing oven, where it is packed in saggars similar to those of the biscuit oven. From there the printed ware is removed to the warehouse, and that requiring further decoration is passed to the enameling department. Here the workers—chiefly women—fill up the printed outline which the ware has already received, with colors, in accordance with the design placed before them.

Another form of decoration found in many china patterns is the addition of a border or coating all over the surface in various colors. This is produced by ground laying, a process consisting of giving the ware a coating of adhesive oil, upon which the color in the form of dust is dabbed upon the surface.

In the gilding department, gold lines are added to the ware, by placing the article on a revolving wheel, which is set in motion by the workman's hand, while he holds the edge of the article. The gold used is the finest that can be obtained, because any alloy would impart to the metal an inferior color.

Finally comes painting on china: the highest class of decoration for pottery.

All articles that are richly decorated with gold upon various colored grounds, or painted upon the glaze, have to be fired in the enamel kiln: an oblong, box-like structure built of fire-bricks and having iron doors. Since no fire whatever penetrates the inside, the structure is very unlike an oven, and is more comparable with a gigantic saggar, with the fire playing around it. The articles are not enclosed in anything, but are arranged upon iron bats supported by short iron props, tier above tier. Then the finished article goes into the wareroom.

EVOLUTION AND NATURE STUDIES

Origin of the Darwinian Theory

By ALFRED RUSSEL WALLACE

WE now approach the subject which, in popular estimation, and perhaps in real importance, may be held to be the great scientific work of the nineteenth century—the establishment of the general theory of evolution, by means of the special theory of the development of the organic world through the struggle for existence and its necessary outcome, Natural Selection. Although in the last century Buffon, Dr. Erasmus Darwin, and the poet Goethe had put forth various hints and suggestions pointing to evolution in the organic world, which they undoubtedly believed to have occurred, no definite statement of the theory had appeared till early in the present century, when La Place explained his views as to the evolution of the stellar universe and of solar and planetary systems in his celebrated Nebular Hypothesis; and about the same time Lamarck published his “*Philosophie Zoologique*,” containing an elaborate exposition of his theory of the progressive development of animals and plants. But this theory gained few converts among naturalists, partly because Lamarck was before his time, and also because the causes he alleged did not seem adequate to produce the wonderful adaptations we everywhere see in nature. During the first half of the present century, owing to the fact that Brazil, South Africa, and Australia then became for the first time accessible to English collectors, the treasures of the whole world of nature were poured in upon us so rapidly that the comparatively limited number of naturalists were fully occupied in describing the new species and endeavoring to discover

true methods of classification. The need of any general theory of how species came into existence was hardly felt; and there was a general impression that the problem was at that time insoluble, and that we must spend at least another century in collecting, describing, and classifying, before we had any chance of dealing successfully with the origin of species. But the subject of evolution was ever present to the more philosophic thinkers, though the great majority of naturalists and men of science held firmly to the dogma that each species of animal and plant was a distinct creation, though how produced was admitted to be both totally unknown and almost, if not quite, unimaginable.

The vague ideas of those who favored evolution were first set forth in systematic form, with much literary skill and scientific knowledge, by the late Robert Chambers in 1844, in his anonymous volume, "Vestiges of the Natural History of Creation." He passed in review the stellar and solar systems, adopted the Nebular Hypothesis, and sketched out the geological history of the earth, with continuous progression from lower to higher forms of life. After describing the peculiarities of the lower plants and animals, dwelling upon those features which seemed to point to a natural mode of production as opposed to an origin by special creation, the author set forth with much caution the doctrine of progressive development resulting from "an impulse which was imparted to the forms of life, advancing them in definite lines, by generation, through grades of organization terminating in the highest plants and animals." The reasonableness of this view was urged through the rest of the work; and it was shown how much better it agreed with the various facts of nature and with the geographical distribution of animals and plants, than the idea of the special creation of each distinct species.

It will be seen, from this brief outline, that there was no attempt whatever to show *how* or *why* the various species of animals and plants acquire their peculiar characters, but merely an argument in favor of the reasonableness of the fact of progressive development, from one species to another, through the ordinary processes of generation. The book was what we

should now call mild in the extreme. It was serious and even religious in tone, and calculated in this respect to disarm the opposition even of the most orthodox theologists; yet it was met with just the same storm of opposition and indignant abuse which assailed Darwin's work fifteen years later. As an illustration of the state of scientific opinion at this time, it may be mentioned that so great a man as Sir John Herschel, at a scientific meeting in London, spoke strongly against the book for its advocacy of so great a scientific heresy as the Theory of Development.

I well remember the excitement caused by the publication of the "*Vestiges*," and the eagerness and delight with which I read it. Although I saw that it really offered no explanation of the process of change of species, yet the view that the change was effected, not through any unimaginable process, but through the known laws and processes of reproduction, commended itself to me as perfectly satisfactory, and as affording the first step toward a more complete and explanatory theory. It seems now a most amazing thing that even to argue for this first step was accounted a heresy, and was almost universally condemned as being opposed to the teaching of both science and religion!

The book was, however, as great a success as, later on, was Darwin's "*Origin of Species*." Four editions were issued in the first seven months, and by 1860 it had reached the eleventh edition, and about 24,000 copies had been sold. It is certain that this work did great service in familiarizing the reading-public with the idea of evolution, and thus preparing them for the more complete and efficient theory laid before them by Darwin.

During the fifteen years succeeding the publication of the "*Vestiges*" many naturalists expressed their belief in the progressive development of organic forms; while in 1852 Herbert Spencer published his essay contrasting the theories of Creation and Development with such skill and logical power as to carry conviction to the minds of all unprejudiced readers; but none of these writers suggested any definite theory of *how* the change of species actually occurred. That was first done in

1858; and in connection with it I may, perhaps, venture to give a few personal details.

Ever since I read the "Vestiges" I had been convinced that development took place by means of the ordinary process of reproduction; but though this was widely admitted, no one had set forth the various kinds of evidence that rendered it almost a certainty. I endeavored to do this in an article written at Sarawak in February, 1855, which was published in the following September in the "Annals of Natural History." Relying mainly on the well-known facts of geographical distribution and geological succession, I deduced from them the law, or generalization, that "Every species has come into existence coincident both in Space and Time with a Pre-existing closely allied Species"; and I showed how many peculiarities in the affinities, the succession, and the distribution of the forms of life were explained by this hypothesis, and that no important facts contradicted it.

Even then, however, I had no conception of *how* or *why* each new form had come into existence with all its beautiful adaptations to its special mode of life; and though the subject was continually being pondered over, no light came to me till three years later (February, 1858), under somewhat peculiar circumstances. I was then living at Ternate in the Moluccas, and was suffering from a rather severe attack of intermittent fever, which prostrated me for several hours every day during the cold and succeeding hot fits. During one of these fits, while again considering the problem of the origin of species, something led me to think of Malthus's Essay on Population (which I had read about ten years before), and the "positive checks"—war, disease, famine, accidents, etc.—which he adduced as keeping all savage populations nearly stationary. It then occurred to me that these checks must also act upon animals, and keep down their numbers; and as they increase so much faster than man does, while their numbers are always very nearly or quite stationary, it was clear that these checks in their case must be far more powerful, since a number equal to the whole increase must be cut off by them every year. While vaguely thinking how this would affect any species, there sud-

denly flashed upon me the idea of *the survival of the fittest*—that the individuals removed by these checks must be, on the whole, *inferior* to those that survived. Then, considering the *variations* continually occurring in every fresh generation of animals or plants, and the changes of climate, of food, of enemies always in progress, the whole method of specific modification became clear to me, and in the two hours of my fit I had thought out the main points of the theory. That same evening I sketched out the draft of a paper; in the two succeeding evenings I wrote it out, and sent it by the next post to Mr. Darwin. I fully expected it would be as new to him as it was to myself, because he had informed me by letter that he was engaged on a work intended to show in what way species and varieties differ from each other, adding, “my work will not fix or settle anything.” I was therefore surprised to find that he had really arrived at the very same theory as mine long before (in 1844), had worked it out in considerable detail, and had shown the MSS. to Sir Charles Lyell and Sir Joseph Hooker; and on their recommendation my paper and sufficient extracts from his MSS. work were read at a meeting of the Linnean Society in July of the same year, when the theory of Natural Selection, or survival of the fittest, was first made known to the world. But it received little attention till Darwin’s great and epoch-making book appeared at the end of the following year.

We may best attain to some estimate of the greatness and completeness of Darwin’s work by considering the vast change in educated public opinion which it rapidly and permanently effected. What that opinion was before it appeared is shown by the fact that neither Lamarck, nor Herbert Spencer, nor the author of the “*Vestiges*,” had been able to make any impression upon it. The very idea of progressive development of species from other species was held to be a “heresy” by such great and liberal-minded men as Sir John Herschel and Sir Charles Lyell; the latter writer declaring, in the earlier editions of his great work, that the facts of geology were “fatal to the theory of progressive development.” The whole literary and scientific worlds were violently opposed to all such theories, and

altogether disbelieved in the possibility of establishing them. It had been so long the custom to treat species as special creations, and the mode of their creation as "the mystery of mysteries," that it had come to be considered not only presumptuous, but almost impious, for any individual to profess to have lifted the veil from what was held to be the greatest and most mysterious of Nature's secrets.

But what is the state of educated literary and scientific opinion at the present day? Evolution is now universally accepted as a demonstrated principle, and not one single writer of the slightest eminence, that I am aware of, declares his disbelief in it. This is, of course, partly due to the colossal work of Herbert Spencer; but for one reader of his works there are probably ten of Darwin's, and the establishment of the theory of the "origin of Species by Means of Natural Selection" is wholly Darwin's work. That book, together with those which succeeded it, has so firmly established the doctrine of progressive development of species by the ordinary processes of multiplication and variation that there is now, I believe, scarcely a single living naturalist who doubts it. What was a "great heresy" to Sir John Herschel in 1845, and "the mystery of mysteries" down to the date of Darwin's book, is now the common knowledge of every clever schoolboy, and of every one who reads even the newspapers. The only thing discussed now is, not the fact of evolution—that is admitted—but merely whether or no the causes alleged by Darwin are themselves sufficient to explain evolution of species, or require to be supplemented by other causes, known or unknown. Probably so complete a change of educated opinion, on a question of such vast difficulty and complexity, was never before effected in so short a time. It not only places the name of Darwin on a level with that of Newton, but his work will always be considered as one of the greatest, if not the very greatest, of the scientific achievements of the nineteenth century, rich as that century has been in great discoveries in every department of physical science.

EVOLUTION AND NATURE STUDIES

Bees in the Hive

By ARABELLA B. BUCKLEY

I AM going to ask you to visit with me to-day one of the most wonderful cities in the world. It is a city with no human beings in it, and yet it is densely populated, for such a city may contain from 20,000 to 60,000 inhabitants. In it you will find streets, but no pavements, for the inhabitants walk along the walls of the houses; while in the houses you will see no windows, for each house just fits its owner, and the door is the only opening in it. Though made without hands, these houses are most evenly and regularly built in tiers one above the other; and here and there a few royal palaces, larger and more spacious than the rest, catch the eye conspicuously as they stand out at the corners of the streets.

Some of the ordinary houses are used to live in, while others serve as storehouses where food is laid up in the summer to feed the inhabitants during the winter, when they are not allowed to go outside the walls. Not that the gates are ever shut; that is not necessary, for in this wonderful city each citizen follows the laws; going out when it is time to go out, coming home at proper hours, and staying at home when it is his or her duty. And in the winter, when it is very cold outside, the inhabitants, having no fires, keep themselves warm within the city by clustering together, and never venturing out of doors.

One single queen reigns over the whole of this numerous population, and you might perhaps fancy that, having so many subjects to work for her and wait upon her, she would do noth-

ing but amuse herself. On the contrary, she, too, obeys the laws laid down for her guidance, and never, except on one or two state occasions, goes out of the city, but works as hard as the rest in performing her own royal duties.

From sunrise to sunset, whenever the weather is fine, all is life, activity, and bustle in this busy city. Though the gates are so narrow that two inhabitants can only just pass each other on their way through them, yet thousands go in and out every hour of the day; some bringing in materials to build new houses, others food and provisions to store up for the winter; and while all appears confusion and disorder among this rapidly moving throng, yet in reality each has her own work to do, and perfect order reigns over the whole.

Even if you did not already know from the title of the lecture what city this is that I am describing, you would no doubt guess that it is a bee-hive. For where in the whole world, except indeed upon an ant-hill, can we find so busy, so industrious, or so orderly a community as among the bees? More than a hundred years ago, a blind naturalist, François Huber, set himself to study the habits of these wonderful insects, and with the help of his wife and an intelligent man-servant, managed to learn most of their secrets. Before his time all naturalists had failed in watching bees, because if they put them in hives with glass windows, the bees, not liking the light, closed up the windows with cement before they began to work. But Huber invented a hive which he could open and close at will, putting a glass hive inside it, and by this means he was able to surprise the bees at their work. Thanks to his studies, and to those of other naturalists who have followed in his steps, we now know almost as much about the home of bees as we do about our own; and if we follow out to-day the building of a bee-city and the life of its inhabitants, I think you will acknowledge that they are a wonderful community, and that it is a great compliment to any one to say that he or she is "as busy as a bee."

In order to begin at the beginning of the story, let us suppose that we go into a country garden one fine morning in May when the sun is shining brightly overhead, and that we see hanging from the bough of an old apple-tree a black object

which looks very much like a large plum-pudding. On approaching it, however, we see that it is a large cluster or swarm of bees clinging to each other by their legs; each bee with its two fore-legs clinging to the two hinder-legs of the one above it. In this way as many as 20,000 bees may be clinging together, and yet they hang so freely that a bee, even from quite the center of the swarm, can disengage herself from her neighbors and pass through to the outside of the cluster whenever she wishes.

If these bees were left to themselves, they would find a home after a time in a hollow tree, or under the roof of a house, or in some other cavity, and begin to build their honeycomb there. But as we do not wish to lose their honey we will bring a hive, and, holding it under the swarm, shake the bough gently so that the bees fall into it, and cling to the sides as we turn it over on a piece of clean linen, on the stand where the hive is to be.

And now let us suppose that we are able to watch what is going on in the hive. Before five minutes are over the industrious little insects have begun to disperse and to make arrangements in their new home. A number (perhaps about two thousand) of large, lumbering bees, of a darker color than the rest, will, it is true, wander aimlessly about the hive, and wait for the others to feed them and house them; but these are the drones, or male bees, who never do any work except during one or two days in their whole lives. But the smaller working bees begin to be busy at once. Some fly off in search of honey. Others walk carefully all around the inside of the hive to see whether there are any cracks in it; and if there are, they go off to the horse-chestnut trees, poplars, hollyhocks, or other plants which have sticky buds, and gather a kind of gum called "propolis," with which they cement the cracks and make them air-tight. Others again, cluster round one bee, blacker than the rest and having a longer body and shorter wings; for this is the queen bee, the mother of the hive, and she must be watched and tended.

But the largest number begin to hang in a cluster from the roof just as they did from the bough of the apple-tree. What

are they doing there? Watch for a little while and you will soon see one bee come out from among its companions and settle on the top of the inside of the hive, turning herself round and round, so as to push the other bees back and to make a space in which she can work. Then she will begin to pick at the under part of her body with her fore-legs, and will bring a scale of wax from a curious sort of pocket under her abdomen. Holding this wax in her claws, she will bite it with her hard, pointed upper jaws, which move to and fro sideways like a pair of pincers; then, moistening it with her tongue into a kind of paste, she will draw it out like a ribbon and plaster it on the top of the hive.

After that she will take another piece; for she has eight of these little wax-pockets, and she will go on till they are all exhausted. Then she will fly away out of the hive, leaving a small wax lump on the hive ceiling or on the bar stretched across it; then her place will be taken by another bee, who will go through the same maneuvers. This bee will be followed by another, and another, till a large wall of wax has been built, hanging from the bar of the hive.

Meanwhile, the bees which have been gathering honey out of doors begin to come back laden. But they cannot store their honey, for there are no cells made yet to put it in; neither can they build combs with the rest, for they have no wax in their wax-pockets. So they just go and hang quietly on to the other bees, and there they remain for twenty-four hours, during which time they digest the honey they have gathered, and part of it forms wax and oozes out from the scales under their body. Then they are prepared to join the others at work and plaster wax on to the hive.

And now, as soon as a rough lump of wax is ready, another set of bees come to do its work. These are called the *nursing bees*, because they prepare the cells and feed the young ones. One of these bees, standing on the roof of the hive, begins to force her head into the wax, biting with her jaws and moving her head to and fro. Soon she has made the beginning of a round hollow, and then she passes on to make another, while a second bee takes her place and enlarges the first one. As

many as twenty bees will be employed in this way, one after another, upon each hole before it is large enough for the base of a cell.

Meanwhile another set of nursing bees has been working just in the same way on the other side of the wax, and so a series of hollows are made back to back all over the comb. Then the bees form the walls of the cells, and soon a number of six-sided tubes, about half an inch deep, stand all along each side of the comb ready to receive honey or bee-eggs.

These cells fit closely into each other; even the ends are so shaped that, as they lie back to back, the bottom of one cell fits into the space between the ends of three cells meeting it from the opposite side, while they fit into the spaces round it. Upon this plan the clever little bees fill every atom of space, use the least possible quantity of wax, and make the cells lie so closely together that the whole comb is kept warm when the young bees are in it.

There are some kinds of bees who do not live in hives, but each one builds a home of its own. These bees—such as the upholsterer bee, which digs a hole in the earth and lines it with flowers and leaves, and the mason bee, which builds in walls—do not make six-sided cells, but round ones, for room is no object to them. But nature has gradually taught the little hive-bee to build its cells more and more closely, till they fit perfectly within each other. If you make a number of round holes close together in a soft substance, and then squeeze the substance evenly from all sides, the holes will gradually take a six-sided form, showing that this is the closest shape into which they can be compressed. Although the bee does not know this, yet as she gnaws away every bit of wax that can be spared, she brings the holes into this shape.

As soon as one comb is finished, the bees begin another by the side of it, leaving a narrow lane between, just broad enough for two bees to pass back to back as they crawl along, and so the work goes on till the hive is full of combs.

As soon, however, as a length of about five or six inches of the first comb has been made into cells, the bees which are bringing home honey no longer hang to make it into wax, but

begin to store it in the cells. When the bee goes to fetch her honey she settles on a flower, thrusts into it her small tongue-like proboscis, which is really a lengthened under-lip, and sucks out the drop of honey. This she swallows, passing it down her throat into a honey-bag or first stomach, which lies between her throat and her real stomach, and when she gets back to the hive she can empty this bag and pass the honey back through her mouth again into the honey-cells.

But if you watch bees carefully, especially in the spring time, you will find that they carry off something else besides honey. Early in the morning, when the dew is on the ground, or later in the day, in moist, shady places, you may see a bee rubbing itself against a flower, or biting bags of yellow dust, or pollen. When she has covered herself with this she will brush it off with her feet, and, bringing it to her mouth, she will moisten and roll it into a little ball, and then pass it back from the first pair of legs to the second, and so to the third or hinder pair. Here she will pack it into a little hairy groove, called a "basket," in the joint of one of the hind legs, where you may see it, looking like a swelled joint, as she hovers among the flowers. She often fills both hind legs in this way, and when she arrives at the hive the nursing bees take the lumps from her, and eat it themselves, or mix it with honey to feed the young bees; or, when they have any to spare, store it away in old honey-cells to be used by and by. This is the dark, bitter stuff called "bee-bread," which you often find in a honey-comb, especially in a comb which has been filled late in the summer.

When the bee has been relieved of the bee-bread she goes off to one of the clean cells in the new comb and, standing on the edge, throws up honey from the honey-bag into the cell. One cell will hold the contents of many honey-bags, and so the busy little workers have to work all day filling cell after cell, in which the honey lies uncovered, being too thick and sticky to flow out, and is used for daily food—unless there is any to spare, and then they close up the cells with wax to keep for the winter.

Meanwhile, a day or two after the bees have settled in the

hive, the queen bee begins to get very restless. She goes outside the hive and hovers about a little while, and then comes in again, and though generally the bees all look very closely after her to keep her indoors, yet now they let her do as she likes. Again she goes out, and again back, and then, at last, she soars up into the air and flies away. But she is not allowed to go alone. All the drones of the hive rise up after her, forming a guard of honor to follow her wherever she goes.

In about half an hour she comes back again, and then the working bees all gather round her, knowing that now she will remain quietly in the hive and spend all her time in laying eggs; for it is the queen bee who lays all the eggs in the hive. This she begins to do about two days after her flight. There are now many cells ready besides those filled with honey; and, escorted by several bees, the queen bee goes to one of these, and putting her head into it, remains there a second, as if she were examining whether it would make a good home for the young bee. Then, coming out, she turns round and lays a small, oval, bluish-white egg in the cell. After this she takes no more notice of it, but goes on to the next cell and the next, doing the same thing, and laying eggs in all the empty cells equally on both sides of the comb. She goes on so quickly that she sometimes lays as many as two hundred eggs in one day.

Then the work of the nursing bees begins. In two or three days each egg has become a tiny maggot or larva, and the nursing bees put into its cell a mixture of pollen and honey which they have prepared in their own mouths, thus making a kind of sweet bath in which the larva lies. In five or six days the larva grows so fat upon this that it nearly fills the cell, and then the bees seal up the mouth of the cell with a thin cover of wax, made of little rings, and with a tiny hole in the center.

As soon as the larva is covered in, it begins to give out from its under-lip a whitish, silken film made of two threads of silk glued together, and with this it spins a covering or cocoon all round itself, and so it remains for about ten days more. At last, just twenty-one days after the egg was laid, the young bee is quite perfect, and begins to eat her way through the cocoon

and through the waxen lid, and scrambles out of her cell. Then the nurses come again to her, stroke her wings and feed her for twenty-four hours, and after that she is quite ready to begin work, and flies out to gather honey and pollen like the rest of the workers.

By this time the number of working bees in the hive is becoming very great, and the storing of honey and pollen-dust goes on very quickly. Even the empty cells which the young bees have left are cleaned out by the nurses and filled with honey; and this honey is darker than that stored in clean cells, and which we always call "virgin honey," because it is so pure and clear.

At last, after six weeks, the queen leaves off laying worker-eggs and begins to lay, in some rather larger cells, eggs from which drones, or male bees, will grow up in about twenty days. Meanwhile, the worker-bees have been building on the edge of the cones some very curious cells which look like thimbles hanging with the open side upward, and about every three days the queen stops laying drone-eggs and goes to put an egg in one of these cells. Notice that she waits three days between each of these peculiar layings, because we shall see presently that there is a good reason for her doing so.

The nursing bees take great care of these eggs, and instead of putting ordinary food into the cell, they fill it with a sweet, pungent jelly, for this larva is to become a princess and a future queen bee. Curiously enough, it seems to be the peculiar food and the size of the cell which makes the larva grow into a mother-bee which can lay eggs, for if a hive has the misfortune to lose its queen, they take one of the ordinary worker-larvæ and put it into a royal cell, and feed it with jelly, and it becomes a queen-bee. As soon as the princess is shut in like the others, she begins to spin her cocoon, but she does not quite close it as the other bees do, but leaves a hole at the top.

At the end of sixteen days after the first royal egg is laid, the eldest princess begins to try to eat her way out of her cell, and about this time the old queen becomes very uneasy, and wanders about distractedly. The reason of this is that there can never be two queen bees in one hive, and the queen knows

that her daughter will soon be coming out of her cradle and will try to turn her off her throne.. So, not wishing to have to fight for her kingdom, she makes up her mind to seek a new home and take a number of her subjects with her. If you watch the hive about this time, you will notice many of the bees clustering together after they have brought in their honey, and hanging patiently, in order to have plenty of wax ready to use when they start, while the queen keeps a sharp lookout for a bright, sunny day on which they can swarm; for bees will never swarm on a wet or doubtful day if they can possibly help it, and we can easily understand why, when we consider how the rain would clog their wings and spoil the wax under their bodies.

Meanwhile the young princess grows very impatient, and tries to get out of her cell, but the worker-bees drive her back, for they know there would be a terrible fight if the two queens met. So they close up the hole she has made with fresh wax, after having put in some food for her to live upon till she is released.

At last a suitable day arrives, and about ten or eleven o'clock in the morning the old queen leaves the hive, taking with her about 2,000 drones and from 12,000 to 20,000 worker-bees, which fly a little way, clustering round her till she alights on the bough of some tree, and then they form a compact swarm ready for a new hive or to find a home of their own.

Leaving them to go their way, we will now return to the old hive. Here the liberated princess is reigning in all her glory; the worker-bees crowd round her, watch over her, and feed her, as though they could not do enough to show her honor. But still she is not happy. She is restless, and runs about as if looking for an enemy, and she tries to get at the remaining royal cells where the other young princesses are still shut in. But the workers will not let her touch them, and at last she stands still and begins to beat the air with her wings and to tremble all over, moving more and more quickly, till she makes quite a loud, piping noise.

Hark! What is that note answering her? It is a low, hoarse sound, and it comes from the cell of the next eldest princess. Now we see why the young queen has been so rest-

less. She knows her sister will soon come out, and the louder and stronger the sound becomes within the cell, the sooner she knows the fight will have to begin. And so she makes up her mind to follow her mother's example and to lead off a second swarm. But she cannot always stop to choose a fine day, for her sister is growing very strong and may come out of her cell before she is off. And so the second, or *after swarm*, gets ready and goes away. And this explains why princesses' eggs are laid a few days apart, for if they were laid all on the same day, there would be no time for one princess to go off with a swarm before the other came out of her cell. Sometimes, when the workers are not watchful enough, two queens do meet, and then they fight till one is killed; or sometimes they both go off with the same swarm without finding each other out. But this only delays the fight till they get into the new hive; sooner or later one must be killed.

And now a third queen begins to reign in the old hive, and she is just as restless as the preceding ones, for there are still more princesses to be born. But this time, if no new swarm wants to start, the workers do not try to protect the royal cells. The young queen darts at the first she sees, gnaws a hole with her jaws, and, thrusting in her sting through the hole in the cocoon, kills the young bee while it is still a prisoner. She then goes to the next, and the next, and never rests till all the young princesses are destroyed. Then she is contented, for she knows no other queen will come to dethrone her. After a few days she takes her flight in the air with the drones, and comes home to settle down in the hive for the winter.

Then a very curious scene takes place. The drones are no more use, for the queen will not fly out again, and these idle bees will never do any work in the hive. So the worker-bees begin to kill them, falling upon them and stinging them to death, and, as the drones have no stings, they cannot defend themselves, and in a few days there is not a drone, nor even a drone-egg, left in the hive. This massacre seems very sad to us, since the poor drones have never done any harm beyond being hopelessly idle. But it is less sad when we know that they could not live many weeks, even if they were not attacked,

and, with winter coming, the bees could not afford to feed useless mouths, so a quick death is probably happier for them than starvation.

And now all the remaining inhabitants of the hive settle down to feeding the young bees and laying in the winter's store. It is at this time, after they have been toiling and saving, that we come and take their honey; and from a well-stocked hive we may even take thirty pounds, without starving the industrious little inhabitants. But then we must often feed them in return, and give them sweet syrup in the late autumn and the next early spring when they cannot find any flowers.

Although the hive has now become comparatively quiet and the work goes on without excitement, yet every single bee is employed in some way either out of doors or about the hive. Besides the honey collectors and the nurses, a certain number of bees are told off to ventilate the hive, for naturally where so many insects are packed closely together the heat will become very great, and the air impure and unwholesome. And the bees have no windows that they can open to let in fresh air, so they are obliged to fan it in from the one opening of the hive. The way in which they do this is very interesting. Some of the bees stand close to the entrance, with their faces toward it, and opening their wings, so as to make them into fans, they wave them to and fro, producing a current of air. Behind these bees, and all over the floor of the hive, there stand others, this time with their backs toward the entrance, and fan in the same manner, and in this way air is sent into all the passages.

Another set of bees cleans out the cells after the young bees are born, and makes them fit to receive honey, while others guard the entrance of the hive to keep away the destructive wax-moth, which tries to lay its eggs in the comb so that its young ones may feed on the honey. All industrious people have to guard their property against thieves and vagabonds, and the bees have many intruders, such as wasps and snails and slugs, which creep in whenever they get a chance. If they succeed in escaping the sentinel bees, then a fight takes place within the hive, and the invader is stung to death.

Sometimes, however, after they have killed the enemy, the

bees cannot get rid of his body, for a snail or slug is too heavy to be easily moved, and yet it would make the hive very unhealthy to allow it to remain. In this dilemma the ingenious little bees fetch the gummy "propolis" from the plant-buds and cement the intruder all over, thus embalming his body and preventing it from decaying.

And so the life of this wonderful city goes on. Building, harvesting, storing, nursing, ventilating, and cleaning from morn till night, the little worker bee lives for about eight months, and in that time has done quite her share of work in the world. Only the young bees, born late in the season, live on till the next year to work in the spring. The queen bee lives longer, probably about two years, and then she, too, dies, after having had a family of many thousands of children.

EVOLUTION AND NATURE STUDIES

The Massacre of the Males

From the "Life of the Bee"

By M. MAETERLINCK

IF skies remain clear, the air warm, and pollen and nectar abound in the flowers, the workers, through a kind of forgetful indulgence, or over-scrupulous prudence perhaps, will for a short time longer endure the importunate, disastrous presence of the males. These comport themselves in the hives as did Penelope's suitors in the house of Ulysses. Indelicate and wasteful, sleek and corpulent, fully content with their idle existence as honorary lovers, they feast and carouse, throng the alleys, obstruct the passages, and hinder the work; jostling and jostled, fatuously pompous, swelled with foolish, good-natured contempt; harboring never a suspicion of the deep and calculating scorn wherewith the workers regard them, of the constantly growing hatred to which they give rise, or of the destiny that awaits them. For their pleasant slumbers they select the snuggest corners of the hive; then, rising carelessly, they flock to the open cells where the honey smells sweetest. From noon till three, when the purple country trembles in blissful lassitude beneath the invincible gaze of a July or August sun, the drones will appear on the threshold. They have a helmet made of enormous black pearls, two lofty, quivering plumes, a doublet of iridescent, yellowish velvet, an heroic tuft, and a fourfold mantle, translucent and rigid. They create a prodigious stir, brush the sentry aside, overturn the cleaners, and collide with the foragers as these return laden with their humble spoil. They have the busy air, the extravagant, con-

temptuous gait of indispensable gods who should be simultaneously venturing towards some destiny unknown to the vulgar. One by one they sail off into space, irresistible, glorious, and tranquilly make for the nearest flowers, where they sleep till the afternoon freshness awakens them. Then, with the same majestic pomp, and still overflowing with magnificent schemes, they return to the hive, go straight to the cells, plunge their head to the neck in the vats of honey, and fill themselves tight as a drum to repair their exhausted strength; whereupon, with heavy steps, they go forth to meet the good, dreamless, and careless slumber that shall fold them in its embrace till the time for the next repast.

But the patience of the bees is not equal to that of men. One morning the long-expected word of command goes through the hive; and the peaceful workers turn into judges and executioners. Whence this word issues, we know not; it would seem to emanate suddenly from the cold, deliberate indignation of the workers; and no sooner has it been uttered than every heart throbs with it, inspired by the genius of the unanimous republic. One part of the people renounce their foraging duties to devote themselves to the work of justice. The great idle drones, asleep in unconscious groups on the melliferous walls, are rudely torn from their slumbers by an army of wrathful virgins. They wake, in pious wonder; they cannot believe their eyes; and their astonishment struggles through their sloth as a moonbeam through marshy water. They stare amazedly round them, convinced that they must be victims of some mistake; and the mother-idea of their life being first to assert itself in their dull brain, they take a step toward the vats of honey to seek comfort there. But ended for them are the days of May honey, the wine-flower of lime-trees and fragrant ambrosia of thyme and sage, of marjoram and white clover. Where the path once lay open to the kindly, abundant reservoirs, that so invitingly offered their waxen and sugary mouths, there stands now a burning bush all alive with poisonous, bristling stings. The atmosphere of the city is changed; in lieu of the friendly perfume of honey, the acrid odor of poison prevails; thousands of tiny drops glisten at the end of the

stings, and diffuse rancor and hatred. Before the bewildered parasites are able to realize that the happy laws of the city have crumbled, dragging down in most inconceivable fashion their own plentiful destiny, each one is assailed by three or four envoys of justice; and these vigorously proceed to cut off his wings, saw through the petiole that connects the abdomen with the thorax, amputate the feverish antennæ, and seek an opening between the rings of his cuirass through which to pass their sword. No defense is attempted by the enormous, but unarmed creatures; they try to escape, or oppose their mere bulk to the blows that rain down upon them. Forced onto their backs, with their relentless enemies clinging doggedly to them, they will use their powerful claws to shift them from side to side; or, turning on themselves, they will drag the whole group round and round in wild circles, which exhaustion soon brings to an end. And, in a very brief space, their appearance becomes so deplorable that pity, never far from justice in the depths of our heart, quickly returns, and would seek forgiveness, though vainly, of the stern workers who recognize only Nature's harsh and profound laws. The wings of the wretched creatures are torn, their antennæ bitten, the segments of their legs wrenched off; and their magnificent eyes, once mirrors of the exuberant flowers, flashing back the blue light and the innocent pride of summer, now, softened by suffering, reflect only the anguish and distress of their end. Some succumb to their wounds, and are at once borne away to distant cemeteries by two or three of their executioners. Others, whose injuries are less, succeed in sheltering themselves in some corner, where they lie, all huddled together, surrounded by an inexorable guard, until they perish of want. Many will reach the door, and escape into space, dragging their adversaries with them; but, toward evening, impelled by hunger and cold, they return in crowds to the entrance of the hive to beg for shelter. But there they encounter another pitiless guard. The next morning, before setting forth on their journey, the workers will clear the threshold, strewn with the corpses of the useless giants; and all recollection of the idle race disappears till the following spring.

EVOLUTION AND NATURE STUDIES

White Ants

By HENRY DRUMMOND

THE termite or white ant is a small insect, with a bloated, yellowish-white body, and a somewhat large thorax, oblong-shaped, and colored a disagreeable oily brown. The flabby, tallow-like body makes this insect sufficiently repulsive, but it is for quite another reason that the white ant is the worst abused of all living vermin in warm countries. The termite lives almost exclusively upon wood; and the moment a tree is cut or a log sawed for any economical purpose, this insect is upon its track. One may never see the insect, possibly, in the flesh, for it lives underground; but its ravages confront one at every turn. You build your house, perhaps, and for a few months fancy you have pitched upon the one solitary site in the country where there are no white ants. But one day suddenly the door-post totters, and lintel and rafters come down together with a crash. You look at a section of the wrecked timbers, and discover that the whole inside is eaten clean away. The apparently solid logs of which the rest of the house is built are now mere cylinders of bark, and through the thickest of them you could push your little finger. Furniture, tables, chairs, chests of drawers, everything made of wood, is inevitably attacked, and in a single night a strong trunk is often riddled through and through, and turned into matchwood. There is no limit, in fact, to the depredation by these insects, and they will eat books, or leather, or cloth, or anything; and in many parts of Africa I believe if a man lay down to sleep with a wooden leg, it would be a heap of sawdust in the morning. So much

feared is this insect now, that no one in certain parts of India and Africa ever attempts to travel with such a thing as a wooden trunk. On the Tanganyika plateau I have camped on ground which was as hard as adamant, and, apparently, as innocent of white ants as the pavement of St. Paul's; and wakened next morning to find a stout wooden box almost gnawed to pieces. Leather portmanteaus share the same fate, and the only substances which seem to defy the marauders are iron and tin.

But what has this to do with earth or with agriculture? The most important point in the work of the white ant remains to be noted. I have already said that the white ant is never seen. Why he should have such a repugnance to being looked at is at first sight a mystery, seeing that he himself is stone blind. But his coyness is really due to the desire for self-protection; for the moment his juicy body shows itself above ground, there are a dozen enemies waiting to devour it. And yet the white ant can never procure any food until it comes above ground. Nor will it meet the case for the insect to come to the surface under the shadow of night. Night in the tropics, so far as animal life is concerned, is as the day. It is the great feeding-time, the great fighting-time, the carnival of the carnivora, and of all beasts, birds, and insects of prey, from the least to the greatest. It is clear then that darkness is no protection to the white ant; and yet without coming out of the ground it cannot live. How does it solve the difficulty? It takes the ground out along with it. I have seen white ants working on the top of a high tree, and yet they were underground. They took up some of the ground with them to the tree-top; just as the Esquimaux heap up snow, building it into the low tunnel-huts in which they live, so the white ants collect earth, only in this case not from the surface, but from some depth underneath the ground, and plaster it into tunneled ways. Occasionally these run along the ground, but more often mount in endless ramifications to the top of trees, meandering along every branch and twig, and here and there debouching into large covered chambers which occupy half the girth of the trunk. Millions of trees in some districts are thus fantastically plastered over with tubes, galleries, and chambers of earth, and many pounds'

weight of subsoil must be brought up for the mining of even a single tree. The building material is conveyed by the insects up a central pipe with which all the galleries communicate, and which at the downward end connects with a series of subterranean passages leading deep into the earth. The method of building the tunnels and covered ways is as follows: At the foot of a tree the tiniest hole cautiously opens in the ground close to the bark. A small head appears, with a grain of earth clasped in its jaws. Against the tree trunk this earth-grain is deposited, and the head is withdrawn. Presently it reappears with another grain of earth; this is laid beside the first, rammed tight against it, and again the builder descends underground for more. The third grain is not placed against the tree; but against the former grain; a fourth, a fifth, and a sixth follow, and the plan of the foundation begins to suggest itself as soon as these are in position. The stones, or grains, or pellets of earth are arranged in a semicircular wall; the termite, now assisted by three or four others, standing in the middle between the sheltering wall and the tree, and working briskly with head and mandible to strengthen the position. The wall in fact forms a small moon-rampart, and as it grows higher and higher it soon becomes evident that it is going to grow from a low battlement into a long perpendicular tunnel running up the side of the tree. The workers, safely ensconced inside, are now carrying up the structure with great rapidity, disappearing in turn as soon as they have laid their stone, and rushing off to bring up another. The way in which the building is done is extremely curious, and one could watch the movements of these wonderful little masons by the hour. Each stone as it is brought to the top is first of all covered with mortar. Of course, without this the whole tunnel would crumble into dust before reaching the height of half an inch; but the termite pours over the stone a moist, sticky secretion, turning the grain round and round with its mandibles until the whole is covered with slime. Then it places the stone with great care upon the top of the wall, works it about vigorously for a moment or two till it is well jammed into its place, and then starts off instantly for another load.

Peering over the growing wall, one soon discovers one, two, or more termites of a somewhat larger build, considerably longer, and with a very different arrangement of the parts of the head, and especially of the mandibles. These important-looking individuals saunter about the rampart in the most leisurely way, but yet with a certain air of business, as if perhaps the one was the master of works and the other the architect. But closer observation suggests that they are in nowise superintending operations, nor in any immediate way contributing to the structure, for they take not the slightest notice either of the workers or the works. They are posted there in fact as sentries; and there they stand, or promenade about, at the mouth of every tunnel, like Sister Anne, to see if anybody is coming. Sometimes somebody does come, in the shape of another ant; the real ant this time, not the defenseless *Neuropteron*, but some valiant and belted knight from the warlike *Formicidæ*. Singly or in troops, this rapacious little insect, fearless in its chitinous coat of mail, charges down the tree trunk, its antennæ waving defiance to the enemy and its cruel mandibles thirsting for termite blood. The worker white-ant is a poor, defenseless creature, and, blind and unarmed, would fall an immediate prey to these well-drilled banditti, who forage about in every tropical forest in unnumbered legion. But at the critical moment, like Goliath from the Philistines, the soldier termite advances to the fight. With a few sweeps of its scythe-like jaws, it clears the ground, and while the attacking party is carrying off its dead, the builders, unconscious of the fray, quietly continue their work. To every hundred workers in a white-ant colony, which numbers many thousands of individuals, there are perhaps two of these fighting-men. The division of labor here is very wonderful; and the fact that besides these two specialized forms there are in every nest two other kinds of the same insect, the kings and queens, shows the remarkable height to which civilization in these communities has attained.

But where is this tunnel going to, and what object have the insects in view in ascending this lofty tree? Thirty feet from the ground, across innumerable forks, at the end of a long

branch, are a few feet of dead wood. How the ants know it is there, how they know its sap has dried up, and that it is now fit for the termites' food, is a mystery. Possibly they do not know and are only prospecting on the chance. The fact that they sometimes make straight for the decaying limb argues, in these instances, a kind of definite instinct; but, on the other hand, the fact that in most cases the whole tree, in every branch and limb, is covered with termite tunnels, would show perhaps that they work most commonly on speculation, while the number of abandoned tunnels, ending on a sound branch in a *cul de sac*, proves how often they must suffer the usual disappointments of all such adventurers. The extent to which these insects carry on their tunneling is quite incredible, until one has seen it in nature with his own eyes. The tunnels are perhaps about the thickness of a small-sized gas-pipe, but there are junctions here and there of large dimensions, and occasionally patches of earth-work are found, embracing nearly the whole trunk for some feet. The outside of these tunnels, which are never quite straight, but wander irregularly along stem and branch, resembles in texture a coarse sandpaper; and the color, although this naturally varies with the soil, is usually a reddish brown. The quantity of earth and mud plastered over a single tree is often enormous; and when one thinks that it is not only an isolated specimen here and there that is frescoed in this way, but often all the trees of a forest, some idea will be formed of the magnitude of the operations of these insects, and the extent of their influence upon the soil which they are ceaselessly transporting from underneath the ground.

In traveling through the great forests of the Rocky Mountains or of the Western States, the broken branches and fallen trunks, strewn the ground breast-high with all sorts of decaying litter, frequently make locomotion impossible. To attempt to ride through these western forests, with their meshwork of interlocked branches and decaying trunks, is often out of the question, and one has to dismount and drag his horse after him as if he were clambering through a wood-yard. But in an African forest not a fallen branch is seen. One is struck at first by a certain clean look about the great forests of the interior, a

novel and unaccountable cleanness, as if the forest bed was carefully swept and dusted daily by unseen elves. And so indeed it is. Scavengers of a hundred kinds remove decaying animal matter, from the carcass of a fallen elephant to the broken wing of a gnat; eating it, or carrying it out of sight and burying it in the deodorizing earth. And these countless millions of termites perform a similar function for the vegetable world, making away with all plants and trees, all stems, twigs, and tissues, the moment the finger of decay strikes the signal. Constantly, in these woods, one comes across what appear to be sticks and branches and bundles of fagots, but when closely examined, they are seen to be mere casts in mud. From these hollow tubes, which preserve the original form of the branch down to the minutest knot or fork, the ligneous tissue is often entirely removed, while others are met with in all stages of demolition. There is the section of an actual specimen, which is not yet completely destroyed, and from which the mode of attack may be easily seen. The insects start apparently from two centers. One company attacks the inner bark, which is the favorite morsel, leaving the coarse outer bark untouched, or more usually replacing it with grains of earth, atom by atom, as they eat it away. The inner bark is gnawed off likewise as they go along, but the woody tissue beneath is allowed to remain, to form a protective sheath for the second company, who begin work at the center. This second contingent eats its way outward and onward, leaving a thin tube of the outer wood to the last, as props to the mine, till they have finished the main excavation. When a fallen trunk lying upon the ground is the object of attack, the outer cylinder is frequently left quite intact, and it is only when one tries to drag it off to his camp-fire that he finds to his disgust that he is dealing with a mere hollow tube, a few lines in thickness, filled up with mud.

But the works above-ground represent only a part of the labors of these slow-moving but most industrious of creatures. The arboreal tubes are only the prolongation of a much more elaborate system of subterranean tunnels, which extend over large areas, and mine the earth sometimes to a depth of many feet or even yards.

The material excavated from these underground galleries and from the succession of domed chambers—used as nurseries or granaries—to which they lead, has to be thrown out upon the surface. And it is from these materials that the huge ant-hills are reared, which form so distinctive a feature of the African landscape. These heaps and mounds are so conspicuous that they may be seen for miles, and so numerous are they, and so useful as cover to the sportsman, that, without them, in certain districts hunting would be impossible. The first things, indeed, to strike the traveler in entering the interior are the mounds of the white ant, now dotting the plain in groups like a small cemetery, now rising into mounds, singly or in clusters, each thirty or forty feet in diameter and ten or fifteen in height; or again standing out against the sky like obelisks, their bare sides carved and fluted into all sorts of fantastic shapes. In India these ant-heaps seldom attain a height of more than a couple of feet, but in Central Africa they form veritable hills, and contain many tons of earth. The brick houses of the Scotch mission-station on Lake Nyassa have all been built out of a single ant's nest, and the quarry from which the material has been derived forms a pit beside the settlement some dozen feet in depth. A supply of bricks as large again could probably still be taken from this convenient depot; and the missionaries on Lake Tanganyika and onward to Victoria Nyanza have been similarly indebted to the labors of the termites. In South Africa the Zulus and Kaffirs pave all their huts with white-ant earth; and during the Boer war our troops in Pretoria, by scooping out the interior from the smaller beehive-shaped ant-heaps and covering the top with clay, constantly used them as ovens. These ant-heaps may be said to abound over the whole interior of Africa, and there are several distinct species. The most peculiar, as well as the most ornate, is a small variety from one to two feet in height, which occurs in myriads along the shores of Lake Tanganyika. It is built in symmetrical tiers, and resembles a pile of small rounded hats, one above another, the rims depending like eaves, and sheltering the body of the hill from rain. To estimate the amount of earth per acre raised from the water-line of the subsoil by white ants.

would not in some districts be an impossible task, and it would probably be found that the quantity at least equaled that manipulated in temperate regions by the earthworm.

These mounds, however, are more than mere waste-heaps. Like the corresponding region underground, they are built into a meshwork of tunnels, galleries, and chambers, where the social interests of the community are attended to. The most spacious of these chambers, usually far underground, is very properly allocated to the head of the society, the queen. The queen termite is a very rare insect, and as there are seldom more than one, or at most two, to a colony, and as the royal apartments are hidden far in the earth, few persons have ever seen a queen; and indeed most, if they did happen to come across it, from its very singular appearance, would refuse to believe that it had any connection with white ants. It possesses indeed the true termite head, but there the resemblance to the other members of the family stops; for the size of the head bears about the same proportion to the rest of the body as does the tuft on his Glengarry bonnet to a six-foot Highlander. The phenomenal corpulence of the royal body in the case of the queen termite is possibly due in part to want of exercise; for, once seated upon her throne, she never stirs to the end of her days. She lies there, a large, loathsome, cylindrical package, two or three inches long, in shape like a sausage, and as white as a bolster. Her one duty in life is to lay eggs; and it must be confessed she discharges her function with complete success, for in a single day her progeny often amounts to many thousands, and for months this enormous fecundity never slackens. The body increases slowly in size, and through the transparent skin the long folded ovary may be seen, with the eggs, impelled by a peristaltic motion, passing onward for delivery to the workers, who are waiting to carry them to the nurseries, where they are hatched. Assiduous attention, meantime, is paid to the queen by other workers, who feed her diligently, with much self-denial, stuffing her with morsel after morsel from their own jaws. A guard of honor in the shape of a few of the larger soldier ants is also in attendance, as a last and almost unnecessary precaution. In addition finally, to the

soldiers, workers, and queen, the royal chamber has also one other inmate—the king. He is a very ordinary-looking insect, about the same size as the soldiers, but the arrangement of the parts of the head and body is widely different, and, like the queen, he is furnished with eyes.

EVOLUTION AND NATURE STUDIES

The Habits of Ants

By SIR JOHN LUBBOCK

THE communities of ants are sometimes very large, numbering even up to 500,000 individuals; and it is a lesson to us, that no one has ever yet seen a quarrel between any two ants belonging to the same community. On the other hand, it must be admitted that they are in hostility not only with most other insects, including ants of different species, but even with those of the same species, if belonging to different communities. I have over and over again introduced ants from one of my nests into another nest of the same species; and they were invariably attacked, seized by a leg or an antenna, and dragged out.

It is evident, therefore, that the ants of each community all recognize one another, which is very remarkable. But more than this, I have several times divided a nest into two halves, and found that even after a separation of a year and nine months they recognized one another, and were perfectly friendly; while they at once attacked ants from a different nest, although of the same species.

It has been suggested that the ants of each nest have some sign or password by which they recognize one another. To test this I made some insensible. First I tried chloroform; but this was fatal to them, and I did not consider the test satisfactory. I decided therefore to intoxicate them. This was less easy than I had expected. None of my ants would voluntarily degrade themselves by getting drunk. I got over the difficulty, however, by putting them into whisky for a few

moments. I took fifty specimens—twenty-five from one nest and twenty-five from another—made them dead drunk, marked each with a spot of paint, and put them on a table close to where other ants from one of the nests were feeding. The table was surrounded as usual with a moat of water to prevent them from straying. The ants which were feeding soon noticed those which I had made drunk. They seemed quite astonished to find their comrades in such a disgraceful condition, and as much at a loss to know what to do with their drunkards as we are. After a while, however, to cut my story short, they carried them all away; the strangers they took to the edge of the moat and dropped into the water, while they bore their friends home into the nest, where by degrees they slept off the effects of the spirit. Thus it is evident that they know their friends even when incapable of giving any sign or password.

This little experiment also shows that they help comrades in distress. If a wolf or a rook be ill or injured, we are told that it is driven away or even killed by its comrades. Not so with ants. For instance, in one of my nests an unfortunate ant, in emerging from the chrysalis skin, injured her legs so much that she lay on her back quite helpless. For three months, however, she was carefully fed and tended by the other ants. In another case, an ant had injured her antennæ in the same manner. I watched her also carefully to see what would happen. For some days she did not leave the nest. At last one day she ventured outside, and after a while met a stranger ant of the same species, but belonging to another nest, by whom she was at once attacked. I tried to separate them; but, whether by her enemy or, perhaps, by my well-meant but clumsy kindness, she was evidently much hurt, and lay helplessly on her side. Several other ants passed her without taking any notice; but soon one came up, examined her carefully with her antennæ, and carried her off tenderly to the nest. No one, I think, who saw it could have denied to that ant one attribute of humanity, the quality of kindness.

The existence of such communities as those of ants or bees implies, no doubt, some power of communication; but the amount is still a matter of doubt. It is well known that if one

bee or ant discovers a store of food, others soon find their way to it. This, however, does not prove much. It makes all the difference whether they are brought or sent. If they merely accompany, on her return, a companion who has brought a store of food, it does not imply much. To test this, therefore, I made several experiments. For instance, one cold day my ants were almost all in their nests. One only was out hunting, and about six feet from home. I took a dead bluebottle fly, pinned it onto a piece of cork, and put it down just in front of her. She at once tried to carry off the fly, but to her surprise found it immovable. She tugged and tugged, first one way and then another, for about twenty minutes, and then went straight off to the nest. During that time not a single ant had come out; in fact, she was the only ant of that nest out at the time. She went straight in; but in a few seconds—less than half a minute—came out again with no less than twelve friends, who trooped off with her, and eventually tore up the dead fly, carrying it off in triumph.

Now, the first ant took nothing home with her; she must therefore somehow have made her friends understand that she had found some food, and wanted them to come and help her to secure it. In all such cases, however, so far as my experience goes, the ants brought their friends; and some of my experiments indicated that they are unable to send them.

Certain species of ants, again, make slaves of others, as Huber first observed. If a colony of the slave-making ants is changing the nest—a matter which is left to the discretion of the slaves—the latter carry their mistresses to their new home. Again, if I uncovered one of my nests of the fuscous ant (*Formica fusca*), they all began running about in search of some place of refuge. If now I covered over one small part of the nest, after a while some ant discovered it. In such a case, however, the brave little insect never remained there; she came out in search of her friends, and the first one she met she took up in her jaws, threw over her shoulder (their way of carrying friends), and took into the covered part; then both came out again, found two more friends and brought them in, the same maneuver being repeated until the whole community was

in a place of safety. This, I think, says much for their public spirit; but seems to prove that—in *F. fusca* at least—the powers of communication are but limited.

One kind of slave-making ant has become so completely dependent on their slaves, that even if provided with food they will die of hunger, unless there is a slave to put it into their mouths. I found, however, that they would thrive very well if supplied with a slave for an hour or so once a week to clean and feed them.

But in many cases the community does not consist of ants only. They have domestic animals; and indeed it is not going too far to say that they have domesticated more animals than we have. Of these the most important are aphides. Some species keep aphides on trees and bushes, others collect root-feeding aphides into their nests. They serve as cows to the ants, which feed on the honey-dew secreted by the aphides. Moreover the ants not only protect the aphides themselves, but also collect their eggs in autumn and tend them carefully through the winter, ready for the next spring. Of the other insects domesticated by ants some, from living constantly underground, have completely lost their eyes and become quite blind.

But I must not let myself be carried away by this fascinating subject, which I have treated more at length in another work. I will only say that though their intelligence is no doubt limited, still I do not think that any one who has studied the life-history of ants can draw any fundamental line of separation between instinct and reason.

When we see a community of ants working together in perfect harmony, it is impossible not to ask ourselves how far they are mere exquisite automatons, how far they are conscious beings. When we watch an ant-hill tenanted by thousands of industrious inhabitants, excavating chambers, forming tunnels, making roads, guarding their home, gathering food, feeding the young, tending their domestic animals—each one fulfilling its duties industriously, and without confusion—it is difficult altogether to deny to them the gift of reason; and all our recent observations tend to confirm the opinion that their mental powers differ from those of men not so much in kind as in degree.

EVOLUTION AND NATURE STUDIES

Spiders and Their Ways

By MARGARET WENTWORTH LEIGHTON

Spider,
At my window spinning,
Weaving circles wider, wider,
From the deft beginning;

Running
Rings and spokes, until you
Build your silken death-trap cunning—
Shall I catch you—kill you?

Sprawling,
Nimble, shrewd as Circe;
Death's your only aim and calling,
Why should you have mercy?

Strike thee?
Not for rapine willful:
Man himself is too much like thee,
Only not so skillful.

—GEORGE HORTON'S *Songs of the Lowly*.

NOT so skillful, and doubtless never will be, for to-day a spider's thread is used in the telescope because man has been unable to manufacture one so fine and delicate.

Whenever I look at the marvelous web of the great black-and-gold garden spider I remember that pretty story of the way in which the group of spiders received its name of *Arachnidae*. In the olden times there was a lovely maiden named

Arachne, who could weave and embroider with such deftness that the nymphs all gathered to watch her. They whispered to each other that she must have been taught by Minerva herself, who was the goddess of Wisdom. Arachne overheard them, and, denying their accusation, challenged Minerva to a trial of skill. Minerva accepted the challenge, and when the webs were woven Arachne's was wonderfully beautiful, but Minerva's far surpassed it. Arachne was in despair and hung herself, whereupon Minerva's chagrin was so great that she transformed her into a spider, and her descendants preserve much of her skill.

We are apt to think of spiders as insects, but really they are only distantly related to insects, their first cousins being scorpions and king crabs. The spider's body consists of two parts. It has four pairs of legs, a pair of palpi, and a pair of mandibles. The legs are jointed, and on the last joint there are three claws. The palpi are used as feelers and to hold the food. The breathing apparatus of the spider is a combination of lungs and gills. It has glands containing poison which lie partly in the head and partly in the basal joint of the mandibles. There is a tiny opening in the claw on the mandible, out of which the poison flows when the spider captures its prey. It has eight eyes. The spiders are classified largely by the different arrangements and grouping of the eyes. Some have them in one or more clusters, some in rows, and others scattered about. They appear to be able to see as well by night as by day. Near the end of the body are the spinnerets—two, three, or four pairs—out of which the silk comes for weaving the webs, nests, and egg cocoons.

Usually the female spider is much larger and stronger than the male. One naturalist thus graphically describes their wedded life: "Their honeymoon is of short duration, and is terminated by the bride's banqueting on the bridegroom. Doubtless she evinces taste and discrimination in her appreciation of a 'nice young man.'"

Spiders, like lobsters and other crustaceans, have the power of reproducing certain parts if they happen to meet with an injury, as legs, palpi, and spinnerets.

We find as marked differences in habits, tastes, and characters among spiders as among human beings. Some kinds prefer always living in houses or cellars, not seeming to care for any fresh air or out-of-door exercise. Mr. Jesse tells of two spiders that lived for thirteen years in opposite corners of a drawer which was used for soap and candles. Others delight in making burrows in the earth, in dwelling under stones or behind the loose bark on trees, and others live under water. Many never leave their webs, but patiently wait, hoping some insect will become entangled in the snares they have set. Others dash about and seize upon every luckless insect that crosses their path. The most adventurous of all are those that sail out into the world on one of their own little threads. Darwin tells of encountering thousands of them many leagues from land when he was taking his famous voyage in the "Beagle." He says: "The little aeronaut, as soon as it arrived on board, was very active, running about, sometimes letting itself fall, then reascending the same thread. It could run with facility on the surface of the water."

In the bright autumn weather, if we observe closely, we may sometimes see some of our own small spiders ascend to the tops of trees, fences, and other high objects, rise on their toes, turn the spinners upward, throw out a quantity of silk, and sail away. They can be seen plentifully any fine day in October or November, before the cold weather, on Boston Common. They grasp the silken thread with their feet and seem to be enjoying themselves as much as the birds and butterflies.

Many instances are recorded of music-loving spiders, perhaps the most interesting being that related by Beethoven's biographer, who says: "A spider weaving its skillful, though delicate, trap for its daily dinner worked industriously in the corner of the ceiling until Beethoven began to play. Beethoven, who at that time had not thousands hanging on his baton, was rather pleased and attached to this listener, which most practically proved the value it attached to the performance by risking its life in coming nearer the enchanted instrument. And ill was it rewarded. The mother one day, perceiving the ugly

animal, seized and killed it. But the boy Beethoven was so put out and so miserable at losing his strange auditor that he burst into tears and, seizing his violin, smashed it against the floor, shivering it into a thousand pieces."

Many kinds build their webs and cocoons in exposed places and take no pains to conceal them, while others cover theirs with tiny pebbles and bits of earth for protection. Some kinds of spiders abandon their egg cocoon as soon as it is finished, while others carry it about with them until the babies appear. One mother allowed herself to be torn to pieces rather than leave her cocoon.

We might compare the spider's different modes of getting about to those of the birds. The hunting spiders leap and hop, the house spiders generally run forward, other kinds run backward and sideways with equal facility, and some, as we have seen, float about in the air. The most marvelous of the spiders' gifts is the silk-spinning. The spinnerets or spinners are little organs at the hind end of the body. Each has a number of very minute holes in it. Out of these the silk flows in a liquid form, but as soon as the air strikes it it hardens into a thread. The strands from the different holes all unite and form what we know as the spider's thread. There are great differences in the kinds of webs and nests which different spiders make. One of the most interesting is the web of the great black-and-gold garden spider. First she spins several lines all joined in the center like the spokes of a wheel, and attached to stems or leaves of plants at the outer edges. When the rays are finished she begins at the middle to make the spiral part. It is fascinating to watch her, as she crosses each spoke, stop and pat down the silk once or twice, then pull it to see if it is well secured before passing to the next one. When the web is finished, she makes a zigzag ladder of white silk, running from the bottom outer edge to the center. When she hangs in the middle of her web, as she does much of the time, the ladder helps to conceal her. The web is made of two kinds of silk—one smooth, the other covered with an adhesive liquid. When the insects are caught, their legs and wings are soon covered with the sticky juice, so that it is impossible for them

to escape. The spider, knowing it would not be convenient to become entangled herself, spins one long, smooth thread from the center to the outside, which she uses in traveling to and fro.

The common house spider is wonderfully sagacious. Once in a while a large insect is caught in her web. She wants to take it up to her inner retreat to devour, and it is too heavy for her to carry. What is she to do? First she bites its leg, injecting some of her poison, which stupefies it. Next she throws some additional threads about it and ascends to the top, pulling the thread as hard as she can. When she has rested for a little time, she winds more threads about her victim and pulls again, each time attaching the threads at the top. In this way she finally succeeds in hoisting her feast into her house, though the process may last several days.

Who would think that our predecessors in the art of curling the hair were spiders? One species has been provided by Nature with a sort of little curling comb called the *calimistra*. It is on the hind legs and consists of two rows of parallel spines. The web, which she makes of bluish-white silk, is unusually pretty, as each thread is gracefully curled by drawing it between the spines.

Thoreau calls the little gossamer webs which we see spread over the grass on a dewy morning the napkins of the fairies. Even Chaucer, who wrote five hundred years ago, mentions them as a great curiosity to the people of his time. He says:

As sore wondren som on cause of thonder,
On ebb and flood, on gossamer and on mist,
And on all thing, 'til that the cause is wist.

A hundred and fifty years ago a Frenchman, M. Le Bon, made some stockings, purses, and gloves from spiders' silk. The Bermuda ladies use the thread of *Nephila* for sewing, and Queen Victoria was presented by the Empress of Brazil with a dress made of spiders' silk.

Spiders molt several times, each time appearing in a different color. We should hardly expect to find very brilliant or showy colors among them, yet some of them are gorgeous in the extreme. A little crab spider that built a house in my gar-

den was the brightest lemon-yellow all over, and shone like a jewel amid the dark green of the surrounding foliage.

One of the English spiders has a black head and thorax, with an orange-red body, on which are six black spots, each ringed with white; another has a green coat with brilliant red and yellow striped trousers, for all the world like a king's jester. One dainty lady is clad in violet and white, a flaunting miss in black and flame-color, and her sister in cherry and brown.

Some of the *Thomisidæ* are the exact colors of certain flowers, in the centers of which they sit all day, watching for the insects that come to get honey.

Two of the spiders' worst enemies are mud wasps and ichneumon flies. In searching recently for spiders beneath the clapboards on the south side of the house, I came across one of those curious structures which the mud wasp builds. I broke it open, and out tumbled a quantity of small spiders. The wasp's storehouse was in three compartments, and all together contained forty-nine spiders, all of the same kind and about the same size, in a torpid condition. The wasp had laid an egg in each of these spiders. She does not kill the spider, but merely stupefies it, so that when her egg hatches the larva may feed upon the luckless spider.

If one be a student of Nature he will perhaps have noticed a spider rush away and hide in her crack without any apparent reason. The moment before she had been enjoying the bright sunshine, and the student wonders why she ran away. The spider's perceptions are so keen that she knows long before he does that the sky will soon be overcast and torrents of rain descend or a cold wind begin to blow. If she stayed out she might soon be benumbed and unable to run into her house.

The water spiders are covered with hairs which shed the water, so that they never get wet. The little house under the water in which they live and raise their families is as snug and dry inside as yours and mine.

No spiders are more interesting than the trapdoor spiders and their first cousins the tarantulas. The former live in Europe and California. First, they make a burrow in the ground and then build the door. The California ones make

their door of mud and sticks. It fits into the tube as a cork does into a bottle. The covers built by the European species are mere little lids, but they are always built so as to resemble the surrounding surface. One kind shows her sagacity by building a sort of double door, by which she can escape should an enemy storm her fort. At the surface is the usual door, and a few inches below this another. When the spider hears an enemy investigating her burrow, she runs below the second door and pushes it up, so that the marauder will think he has happened upon a empty nest, the second door forming the bottom of it. The babies are born in the tubes, and remain with their mother until they are able to make nests for themselves.

These spiders spend the days in their burrows, but at night they all flock out to enjoy themselves. They fasten open their doors and make little webs over the grass. Many night-wandering beetles are caught, and then comes the banquet, which consists of the softer parts of the beetles. In the morning the closest observer could not find a trace of the preceding night's revelry, so carefully have the spiders cleared away all webs, beetle legs, and wing covers.

One group of spiders is called *Lycosa*, which means wolf spider. Perhaps they were named from the similarity of their habits to those of the wolf, being like him wandering and predaceous.

One of these is the tarantula, a great hairy fellow who inhabits warm countries. The species received its name from the Italian city of Tarentum, where they have been found in large numbers. There is a curious superstition connected with the tarantula's bite. If a person was bitten it was thought nothing could save his life but the playing of some lively dancing tunes. When he heard these he was supposed to be unable to resist the temptation to dance. Thus he grew very warm, and the perspiration came out in great beads all over him, each bead filled with poison. After he had danced as long as he possibly could, the poison had all escaped from his system. The tarantulas feed on small birds as well as insects. Indeed, one of the great southern species is called the bird-catching spider.

In India, where all animals are treated with consideration and even reverence, the little children often keep these spiders for pets. They tie a cord round a spider and lead it about, feeding it with worms and insects. Mother *Lycosa* always carries her egg cocoons out with her on her hunting expeditions, attached to the spinnerets.

One summer I kept a garden spider for three weeks under a tumbler, and had the pleasure of watching her building her house of snowy silk, with its three entrances, and raising a large family of children. She soon learned to take flies from my hand and drink water from a leaf which I gave her fresh every day. After a time she seemed to languish and droop, so I set her free in the garden once more.

If you wish to live and thrive,
Let a spider run alive.

says the old Kentish proverb.

EVOLUTION AND NATURE STUDIES

The Nocturnal Migration of Birds

By FRANK M. CHAPMAN

NO branch of ornithology offers more attractions to the student of birds than the fascinating subject of migration. Birds come and go; absent to-day, to-morrow they greet us from every tree and hedgerow. Their departure and arrival are governed by as yet unknown laws; their journeys though the pathless sky are directed by an instinct or reason which enables them to travel thousands of miles to a winter home, and in the spring to return to the nest of the preceding year. Volumes have been written to explain their mysterious appearances and disappearances.

Theories almost as numerous as the essays themselves have been advanced to account for the phenomena of migration. From the time of Jeremiah (viii. 7) to the present day we might cite a host of authors who have contributed to the literature of the subject. It is not our intention, however, to review the whole question of migration. The combined researches of ornithologists have placed it among the sciences, and its more prominent facts are common knowledge. We desire here to call attention to but one phase of the study, and more especially to outline some recent investigations in connection with the nocturnal migrations of birds.

From the nature of the case, our data concerning these night flights have long been meager and unsatisfactory. Even now our information has but reached a stage which permits us to intelligently direct further effort.

We know that the land birds which migrate by night in-

clude species of more or less retiring disposition, whose comparatively limited powers of flight would render them easy victims for birds of prey if they ventured far from the protection of their natural haunts during the day. Thus we find that the bush- or tree-loving thrushes, wrens, warblers, and vireos all choose the night as the most advantageous time in which to make their long semi-annual pilgrimage, while such bold rovers as swallows, swifts, and hawks migrate exclusively by day.

The information we possess concerning the manner in which the first-mentioned class of birds accomplish a journey which leads them from boreal regions to the tropics, has been derived from three sources: First, through the birds which are killed by striking lighthouses or electric-light towers; second, through observations made at night from similar structures; and, third, through the use of the telescope.

It has long been known that lighthouses are most destructive to night-migrating birds. Probably no one artificial cause produces more disastrous results than these beacons which guide the mariner in safety, but prove fatal obstacles in the path of aerial voyagers.

The number of birds killed by striking lighthouses is incalculable. Over fifteen hundred have been found dead at the foot of the Bartholdi statue in a single morning; while from Fire Island (Long Island) light we have a record of two hundred and thirty birds of one species—black-poll warblers which met their fate on the night of September 30, 1883.

Reports from numerous lighthouses show (1) a great variation in avian mortality at different localities; (2) that as a rule no birds are killed during clear nights; and (3) that comparatively few birds strike the lights during the vernal migration. The fact that birds follow certain routes or highways of migration in their journeys to and from the South doubtless explains their absence or presence at a given locality; indeed, it has been definitely ascertained that lights which are situated in known lines of migration—as for example, the Bartholdi statue at the mouth of the Hudson River valley—prove far more destructive than those which are placed far from the regular routes of migrating birds.

Through telescopic observations, to be mentioned later, we have learned that when *en route* birds travel at an altitude of from one to three miles above the earth. It is obvious, then, that when their way is not obscured by low-hanging clouds they pass too far above us to be attracted by terrestrial objects. It has been noted that cloudy and especially rainy nights are most disastrous to migrants, evidently because the formation of moisture at the elevation at which they are flying must not only interfere with their progress, but, also because, in veiling the earth below, it robs them of their landmarks, while the condensation of this moisture into rain presents an effectual check to flight. The birds then descend to a lower altitude, and, should the storm be very severe, they are obliged to seek the nearest shelter, and may even be driven to earth wet, helpless, and dying.

The influence thus shown to be exerted by meteorological conditions is the best explanation of the comparatively small number of birds killed during the spring migration, when the infrequency of violent storms enables them to perform their journey with less danger from exposure to the elements.

The observations of Mr. William Brewster on the migration of birds at the Point Lepreaux (Bay of Fundy) lighthouse have never been exceeded in interest or value by the recorded experiences of any other observer of similar phenomena. Still, even his graphic account fails to produce the sensations which possess one when for the first time the air at night is actually seen to be filled with the tiny songsters which before were known only as timid haunters of woods and thickets.

On September 26, 1891, it was the writer's good fortune to pass the night with several ornithologists at the Bartholdi statue in observing the nocturnal flight of birds. The weather was most favorable for our purpose. From the balcony at the base of the statue we saw the first bird enter the rays of light thrown out by the torch, one hundred and fifty feet above us, at eight o'clock. During the two succeeding hours birds were constantly heard and many were seen. At ten o'clock a light rain began to fall and for three hours it rained intermittently. Almost simultaneously there occurred a marked increase in

the number of birds seen about the light, and within a few minutes there were hundreds where before there was one, while the air was filled with the calls and chirps of the passing host.

The birds presented a singular appearance. As they entered the limits of the divergent rays of light they became slightly luminous, but as their rapid wing-beats brought them into the glare of the torch they reflected the full splendor of the light, and resembled enormous fireflies or swarms of huge golden bees.

At eleven o'clock we climbed to the torch and continued our observations from the balcony by which it is encircled. The scene was impressive beyond description; we seemed to have torn aside the veil which shrouds the mysteries of the night, and in the searching light reposed the secrets of Nature. As the tiny feathered wanderers emerged from the surrounding blackness, appeared for a moment in the brilliant halo about us, and continuing their journey were swallowed up in the gloom beyond, one marveled at the power which guided them thousands of miles through the trackless heavens. While by far the larger number hurried onward without pausing to inspect this strange apparition, others hovered before us like humming-birds before a flower, then wheeling, retreated for a short distance and returned to repeat the performance or pass us as did the first class mentioned, while others still, and the number was comparatively insignificant, struck some part of the torch either slightly or with sufficient force to cause them to fall stunned or dying. It was evidently by the merest accident that they struck at all; and, so far as we could judge, they were either dazzled by the rays of the light and thus unwittingly flew directly at the glass which protects it, or came in contact with some unilluminated part of the statue. During the two hours we were in the torch thousands of birds passed within sight, but less than twenty were killed.

This fact, in connection with the comparative or entire absence of birds on clear nights, very plainly shows that conclusions based solely on these casualties may be not only misleading but also erroneous. In other words, the number of birds

which strike a light is a poor index to the number which have flown by or above it in safety.

Throughout the evening there was a more or less regular fluctuation in the number of birds present; periods of abundance were followed by periods of scarcity, and the birds passed in well-defined flights, or loose companies, probably composed in the main of individuals which had started together.

The birds chirped and called incessantly. Frequently, when few could be seen, hundreds were heard passing in the darkness; the air was filled with the lisping notes of warblers and the mellow whistle of thrushes, and at no time during the night was there perfect silence. At daybreak a few stragglers were still winging their way southward, but before the sun rose the flights had ceased. The only birds identified were several species of warblers and thrushes, one red-eyed vireo, two golden-winged woodpeckers, one catbird, one whip-poor-will, and one bobolink. The most interesting and important results of the night's observations were the immediate effect of rainfall in forcing birds to migrate at a lower level, the infrequency with which they struck the torch, the immense number which passed beyond its rays, and the constancy with which they called and chirped as they flew.

An almost virgin field awaits the investigator who will systematically observe night-migrating birds with the aid of a telescope. Messrs. Allen and Scott, at Princeton, and the writer, assisted by Mr. John Tatlock, Jr., at Tenaflly, New Jersey, and at the Columbia College Observatory, have alone recorded the results of observations of this nature. Their labors, however, were too brief to show more than the possibilities which await more extended effort.

A comparatively low-power glass is focused upon the moon, the birds appearing silhouetted upon its glowing surface as they cross the line of vision. Some idea of the multitude of feathered forms which people the upper regions of the air at night may be formed when it is stated that during three hours' observation at Tenaflly no less than two hundred and sixty-four birds were seen crossing the restricted field included in the angle subtended by the full moon. Under proper focal condi-

tions, birds were so plainly visible that in many instances marked character of flight or form rendered it possible to recognize the species. Thus ducks, snipe, and sora rail were distinguished with certainty.

The effect on the observer of this seeing of things unseen is not a little curious, and may be likened to the startling disclosures which a high-power microscope presents in a drop of water.

From calculations based on an assumption that birds were not visible beyond a distance of five miles, we determined the greatest altitude at which birds migrate to be three miles above the earth's surface. Many, however, fly at a lower level; indeed, it is not improbable that certain species may, with more or less regularity, travel at a given altitude, and that this altitude may vary among birds of different families. With little doubt thrushes and warblers travel at a much lower level than do ducks and geese, a circumstance which may account for the great abundance of the first two named and the comparative absence of the last in the vicinity of lighthouses.

Such, in brief, are the sources and methods to which we owe our knowledge of the nocturnal flight of birds. It will be evident to the most casual reader how incomplete are our data. The time is still far distant when we can hope to account conclusively for the many perplexing phenomena of migration, but we may be pardoned if, in conclusion, we briefly review the bearing of our present information.

We need not discuss here the origin of migration or the causes which now induce birds to undertake a long and perilous journey twice each year. But the power and influences which guide a bird, in the darkness of the night, through space, and render a definite migration possible, are subjects kindred to our inquiry and worthy our attention.

Until we possess some exact knowledge of the distance to which birds can see we cannot estimate the aid their vision is to them while migrating. We know, however, that the avian eye is far more powerful than ours, and it is fair to assume that to some extent their journeys are directed by a sight which enables them to follow mountain chains, river valleys, and

coast lines, and to distinguish distant headlands or islands. At an altitude of two miles an object would be visible ninety miles and the horizon be separated by twice this distance. At no time, therefore, in their journey from North to South America are birds necessarily out of sight of land. But that they do venture beyond a point where land is visible is shown by the regular appearance of migrants in the Bermudas, six hundred miles from our coast, while Jamaica, four hundred miles north of the nearest point of South America, is a point of departure for many south-bound migrants. Here, with neither islet, shoal, nor reef to mark the way, it is evident that sight alone would prove an insufficient guide, and they must rely on some other sense. Primarily, this is the inherited habit which prompts birds to fly southward in the fall and to return in the spring. But, given the impulse of direction, there is little doubt that one of the best guides to night-flying birds is the sense of hearing. Birds' ears are exceedingly acute. They readily detect sounds which to us are inaudible. Almost invariably they will respond to an imitation of their notes. We have seen that when under way they constantly chirp and call, and when we take into consideration their aural power and their abundance in highways of migration, it is probably that at no time during the night is a bird out of hearing of its fellow-travelers. The line of flight once established, therefore, presumably by the older and more experienced birds, it becomes a comparatively easy matter for the novice to join the throng.

EVOLUTION AND NATURE STUDIES

Wingless Birds

By PHILIPPE GLANGEAUD

IT is often said that there are no rules without exceptions. We purpose to test the truth of this maxim once more. Fishes are made to live in water, but some of them pass the greater part of their existence in mud. Some even perch upon trees, thus competing with birds, whose kingdom is the air, and which are able, with the aid of their wings, to plunge into space and travel rapidly over considerable distances. Yet there are birds, deprived by Nature, which do not possess the wing characteristic of the feathered tribe, and are, consequently, like the majority of animals, pinned to the soil.

Birds do not all have equal power of flight, which is closely related to the extent of the development of their wings. There exist all grades in the spread of wings, between that of the condor, which is four times the length of the body, whereby the bird is able to rise to the height of nearly twenty-five thousand feet, and the little winglets of the auk, which are of no use to it. The penguins have still smaller wings, which are nothing more than short, flattened stumps, without proper feathers and covered with a fine, hairlike down which might be taken for scales.

Another group of birds exists, called appropriately *Brevipennes*, the wings of which are so poorly developed as to be wholly unsuitable for flight. As an offset and just compensation for this, their long and robust legs permit them to run with extraordinary speed. For that reason they have been called running birds, in distinction from other kinds that con-

stitute the group of flying birds. Among them are some gigantic birds, and also some that have no visible wings on the outside of their bodies, and may therefore be properly called wingless.

The ostrich is a member of this group. With its bare, callos head and short bill, its long, featherless neck, and its massive body, supported by long, half-bare legs, ending in two large toes; its very short wings, formed of soft and flexible feathers; and its plume-shaped tail, it presents a very special appearance among the birds.

The nandou, the American representatives of the ostrich, have still shorter wings, which have no *remigia* at all, and terminate in a horny appendage; they have no tail feathers.

The cassowary and the emu also resemble the ostrich in many points, but their wings are still more reduced than those of the nandou. They are only slightly distinct, and cannot be seen when the bird holds them close to its body. In the *Apteryx*, the name of which, from the Greek, means without wings, the organs of flight are hardly apparent, and consist simply of a very short stump bearing a thick and hooked nail. The *Apteryx*, which is also called *Kiwi*, a native of New Zealand, is the most singular of living birds. The neck and the body are continuous, and the moderately sized head is furnished with a long beak resembling that of the ibis. Having long hairs similar to the mustaches of cats at its base, it is different from the bills of all other existing birds in possessing nostrils that open at its upper point. Although the *Apteryx* cannot fly, it runs very fast, despite the shortness of its legs, and can defend itself very effectively against assailants by the aid of its long-nailed and sharp-nailed feet. The tail is absent like the wings. The very pliant feathers are extremely curious, of the shape of a lance-head, pendant, loose, silky, with jagged barbs, and increase in length as they go back from the neck. The bird is of the size of a fowl, and when in its normal position stands with its body almost vertical, and carries the suggestion of a caricature—resembling, we might say, a feathered sack, with only a long-billed head and the claws projecting, so that one beholding it feels that he is looking at some unfinished crea-

ture. It is a nocturnal bird, of fierce temper, and has become rare in consequence of the merciless war that is made upon it. Everything is strange about it, even the single egg it lays, which weighs about a quarter as much as its body.

Together with the *Apteryx* there lived, in New Zealand a bird that reached the height of nearly twelve feet—the *Dinornis*. It and the *Phororhaces* and the *Brontornis*, which have been recently exhumed in Patagonia, might be regarded as the giants of birds. This bird was known to the natives as the *Moa*, and lived in troops like the ostriches. Its organization was very much like that of the *Apteryx*, from which it was distinguished, however, by its great size, long neck, and short beak. It seems to have had the aspect of an ostrich, with a feathered neck and no wings or tail. The feet of the *Dinornis*, with their three large toes, were really enormous. Isolated fragments of its bones suggest very large mammals, rather than birds. The femur and tibia are larger than those of a bear, the tibia alone being about four feet long, and the thickness, in the narrowest part, of the width of a man's hand, while it was more than seven inches in the thickest part. The sternum, on the other hand, was small, convex, and longer than broad. The wings could not have been visible on the outside of the body, for the bones that constitute them are proportionally smaller than those of the *Apteryx*. There was, therefore, a maximum reduction of the wing in this bird.

The *Dinornis* was covered with a rich plumage, and this was doubtless what led to its destruction, women preferring its plumes to all other ornaments. The large number of bones which have been discovered in the alluviums, the caves, and the peat bogs of New Zealand authorize the thought that the island was once inhabited by a considerable number of these birds, which were able easily to repel the attacks of other animals by means of their big feet. But they could stand no chance against Nature's more terrible destroyer—man—who, when seeking the gratification of his taste and fancy, does not hesitate to exterminate whole species. The natives of New Zealand still recall the history of these singular birds; their extermination seems to have occurred about the time the island was

visited by Captain Cook (1767-1778). Moreover, some of the bones collected in later years still had animal matter upon them. Even parts of the windpipe have been discovered, mixed with charcoal, and evidences of cooking have been found.

A near relative of the *Dinornis*, which the Maoris regard as extinct, is the *Notornis*, of which only four living specimens have been found since 1842, the last one having been captured in the latter part of 1898.

The eggs of the *Dinornis* were very large, having a capacity of about a gallon and being equivalent to eighty hen's eggs. Still larger eggs than these, however, are known. In 1851 Isidore Geoffroy Saint-Hilaire exhibited, in the French Academy of Sciences, eggs of a bird coming from Madagascar that had a capacity of two gallons. Some specimens of these eggs may be seen in the galleries of the Paris Museum, and still larger eggs have been found. The museum in London has one with a capacity exceeding eleven quarts, or equivalent to two hundred and twenty hen's eggs, or more than seventy thousand humming-birds' eggs. It was thought at first that the bird which laid these gigantic eggs was still living, for natives of Madagascar spoke of having seen a bird of colossal size that could throw down an ox and make a meal of it. Such, however, were not the ways of the bird called the *Epiornis*, which had no talons or wings, and fed on vegetable substances. The description by the celebrated traveler Marco Polo of a great flying bird of prey, called a roc, has no reference to the *Epiornis*. M. Grandidier has demonstrated that this bird no longer exists in Madagascar, and that, if man ever knew it, the stories with marvelous details which the savages hand down from generation to generation make no mention of it. We owe to M. Grandidier, M. Milne-Edwards, and Major Forsyth what is known of the history of this large wingless bird, which resembles the *Dinornis* in several points. If its size was proportioned to that of its eggs it should have been twice as large as the *Dinornis*. It was not, however, but constituted a family represented by very diverse forms and of variable size, though never much exceeding eleven feet. The head was similar in appearance to that of the *Dinornis*, but the surface of the fore-

head was furrowed with wrinkles and cavities, indicating the presence of a crest of large feathers. A curious peculiarity was the opening of the Eustachian tube directly on the exterior. The cervical vertebræ are very numerous, while the sternum is much reduced. It is a flat bone, broad but very short, especially in the median part. The wing also has suffered a great regression, for it comprises only a thin, short rod, the humerus, and a small osseous mass representing all the other bones of the wing stuck together. The *Epiornis* had no wings externally visible. The bones of the feet were, on the other hand, of considerable size, and indicate that the bird that possessed them was larger than the *Dinornis*.

The *Epiornis*, according to M. Milne-Edwards, frequented the borders of waters, keeping among the reeds along lakes and rivers, for its bones are found associated with those of turtles, crocodiles, and a small hippopotamus. It most probably nested in the low plains around lakes.

Just as the *Apteryx* among birds, and the bison and the beaver among mammals, so the *Dinornis* and the *Epiornis* have been destroyed as man has extended his abode and his domination.

When we regard the fauna of Madagascar and of New Zealand we are struck by the great resemblance between them, from the points of view of their recent and ancient vertebrate fauna. These resemblances suggest the past existence of relations between these two lands now separated by a wide expanse of sea, and this agrees with geological observations.

EVOLUTION AND NATURE STUDIES

The Cobra and Other Serpents

By G. R. O'REILLY

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DURING a three years' residence in southern Africa cobras and other snakes were my pets and most intimate companions. They occupied my bedroom; they sunned themselves in my windows; they coiled themselves in my armchair and on my study table, and made themselves quite at home among my book-shelves and bric-a-brac. Baby cobras were born into my hands, and adult cobras accompanied me, coiled in my pocket, whenever I went out to take sly observations, through a binocular glass, of the movements of their brothers and sisters still free among the rocks and bushes of plain or hillside.

Above all his peers in the ophidian kingdom, the royal cobra claimed my chief attention. His beauty, the web of Oriental romance in which his name is intertwined, and the dreadful destruction of human life with which he is credited, make him to all of us an exceedingly interesting animal. As man alone stands up and walks erect, the acknowledged king among living things, so it is only the cobra of all the reptile kind that raises himself perpendicularly from the ground and expands his neck as if in fancied pride of his power to dispute with humanity the supremacy over animal life. Year after year, over the whole of Southern Asia, but especially in the Indian Peninsula, a vast multitude of men, women, and children fall victims to his deadly fangs. If each year, within the bounds of British India alone, a town of 10,000 inhabitants were to be utterly depopulated by

a painful form of death, and if this calamity had been constantly recurring, as far back through the centuries as history has record of, who would not be filled with commiseration for a people so afflicted? And yet in that same country this number of human beings is annually carried off by the bite of poisonous serpents, and the world looks for it as a matter of course. Thus the dreaded cholera itself is not a greater destroyer of human life, as it is but an occasional visitant. As the cobra is blamed for nearly all this appalling mortality, we need not seek out further reason for giving him the title of "king of deadly serpents."

Sir Joseph Fayrer, in his magnificent "Thanatophidia of India," gives us copious information regarding his poison, its terrible work among the Indian peoples, and the various methods of counteracting its effects; and more recently our own able inquirer, Dr. Weir Mitchell, has given us its analysis. But as regards the story of cobra life itself, cobra capabilities, and cobra idiosyncrasies, we are still at the mercy of Pliny and his successors. From book to book the old yarns of his fondness for milk and his susceptibility to music are handed down as heirlooms, and will continue to find believers until writing naturalists keep living cobras at their elbows.

Under the general name "cobra" are included several species, differing little in general appearance. They are found all over southern Asia and throughout the entire continent of Africa. In India, *Naja tripudians* is common; in North Africa, *Naja haja*; and in South Africa, *Sepedon hæmachates*. In the other continents no true cobra exists. They are all hooded snakes, and all exceedingly venomous. In color they vary much; some are yellow, some are brown, others black—while in general all are banded more or less distinctly with regular light and dark rings. They are usually about four feet in length and two inches in diameter, but can attain to six feet.

All terrestrial deadly serpents may be divided into two groups—the *Viperidæ*, which have the head covered with small, irregular scales; and the *Elapidæ*, which have it covered with large, regularly disposed plates. Taking the rattlesnake as the representative of the *Viperidæ* and the cobra of the *Elapidæ*, it will

be instructive to note some of the differences between these two famous poisoners. The head in the rattler is broad and flat and the neck very thin; its body increases in diameter toward the middle and gradually tapers off to the tail. In the cobra the head, neck, and body are of the same thickness until the tail commences. In the rattlesnake the eyes have a vertical pupil, like a cat's; in the cobra the pupil is round. In the rattlesnake the fangs are long, well curved, very movable, thin, and with the end of the poison duct coming out almost in the same line with the point of the fang; in the cobra the fang is very short, slightly curved, scarcely movable, strong, and with the end of the poison duct coming out at a large angle with the point. In disposition the rattler is much more sluggish and not nearly so timorous as the cobra. To meet an assailant, the rattlesnake will arrange himself coiled carefully, like a spring, in a horizontal position; while the cobra prepares no coil, but raises himself up on high, perpendicular from the ground. As to the manner of securing their prey, the rattlesnake is like a cat: he lies in wait for it in a suitable locality, and then springs on it unawares, generally waiting till its death struggles have ceased before swallowing it. The cobra, on the contrary, hunts up his victims, pursues them like a dog, and swallows them alive when caught. There is also, as Dr. Weir Mitchell has shown, a marked chemical variance between their poisons.

All these differences are, as a rule, applicable to their respective classes; and it is worthy of mention that in the several points enumerated, excepting as regards the poison arrangements, the *Viperidæ* agree with the true boas and the *Elapidæ* with the colubrine or common harmless snakes. So it will be understood that the cobra is rather a cousin to the black snake than to the rattler.

In searching for his prey, he glides about without anything remarkable in his appearance to denote that he is a cobra; but, when excited by fear or anger, he raises his head and from one-third to one-half of his body perpendicularly from the ground, while the remainder is gathered beneath into a coil of support. At the same time the upper ribs, from the head downward for five or six inches or more, spread themselves out

laterally, carrying the skin with them, thus making of his neck a thin, flattened oval disk four or five inches broad. This wide flatness of the neck is called the "hood," and above it the head appears pointing horizontally to the front. His disposition is so extremely nervous and timid that he will strike at a moving adversary long before he comes near enough to reach him with effect. If you stand before a cobra thus erect and alarmed, and move alternately your left and right hands up and down, he will strike repeatedly to the left and right, following your motions, bringing his head and neck flat on the ground each time, and at every stroke drawing closer to you. In striking thus he hisses audibly and instantly reassumes his erect position, and thus he continues to act as long as danger menaces or a safe avenue of escape does not present itself. This turning to the left and right after one's movements and striking downward is the so-called "dancing," which superficial observers have attributed to the power of music. Even after a slight acquaintance with snake dancing I began to suspect that music had nothing to do with it. Before long I was convinced on the subject.

It happened, I believe, in 1877, that Sir Bartle Frere, Governor of the British dominions in South Africa, when on his way eastward to settle some troubles preceding the outbreak of the war with the southern Kaffirs, paid a visit to my collection at Grahamstown. He arrived unexpectedly and found me on my knees with my sleeves rolled up, washing out my floor, for it was impossible to get a servant to enter the room. Seeing there all the snakes of the country living before him, he was intensely interested, and at once singled out the cobra as an old acquaintance, for he had spent much of his life in India. Many things he told me of Indian snake-charming; but when I made the cobras dance, faint away as if dead, and by a touch return them to life again, he asked in some astonishment how it happened that I did so without the aid of music. I explained the "dancing" as the natural tactics of the cobra in defense and attack, and the fainting and recovery as consequences of an extremely nervous and over-excitable temperament. But my visitor clung to his old opinion, saying that my

belief that they never really danced to the music was opposed to the teachings of natural history and to the experience of every one who had lived in India.

Next day, when the astute Sir Bartle was on his way to the frontier to charm the turbulent chiefs with diplomacy, I invited a flute-player to charm my snakes. I myself went into the room to note results and sat down in my usual place among my pets, leaving the musician outside in the hall, so placed that the snakes could not see him. He played his sweetest tunes. The "Last Rose of Summer," "Annie Laurie," and "Home, Sweet Home" had no effect, so I called to him to play something quick and lively. Accordingly, he gave us "Pop goes the Weasel," "Miss McLeod's Reel," and "The White Cockade"; but never a snake moved. I then invited him inside, but the result was the same, the flute was a failure. Next day I tried the violin. The performer again sat outside, but all his efforts were useless; both quick and slow music were alike lost upon them. On my invitation he came in and sat still a few moments preparatory to commencing afresh. He soon thought himself an Orpheus; for, as he began playing, the cobras stood upon the floor. "Aha!" said he, "see that!" However, believing that they were only alarmed at the quick movements of his arm, I stood over between him and them, thus cutting off their view, whereupon they showed that their fears were quieted by gently lowering themselves to the floor.

On the table was a glass-fronted wooden box in which was a large puff adder. I got the musician to sit close opposite to this and play his loudest, but the snake never showed the slightest sign. Then, at my request, he went round behind the cage and let one end of the violin rest on the top of it. At first he played the higher notes, and the snake showed no sign; but when he touched the deep bass chords the animal swelled himself up and began to blow as if alarmed. Thus, from the instrument resting on the wood of the top, the vibration was conveyed to the whole box, and the snake *felt* it throughout his entire body where he lay in contact with it, in the very same way that I myself *felt* it when I laid my hand upon it.

Many trials were made with other instruments, but always

with the same results, viz., 1. Music from an unseen performer had no effect whatever. 2. If the performer were seen, any noticeable movements of his would alarm the snakes, but in exactly the same way as if he made no noise at all. 3. They gave signs of disturbance when the vibration, especially of bass sounds, was communicated to the material on which they lay.

Thus was proved not only that cobras do *not* dance to music, but that, far from being charmed with the melody, the poor animal is only *frightened* at the movements of the musician, and that the apparent dancing and bowing are only so many half-hearted attempts to strike at the performer or some one moving in his vicinity. Furthermore, I was led to the conclusion that *snakes cannot hear any sound* with sufficient distinctness to determine their acts, unless it is so great as to cause objects in contact with their skin to *vibrate sensibly to the touch*, and that even then they can only be said to feel *the sound's effect*.

At the present moment, as I write, there is on the table before me a glass-fronted box in which are some of our common garter snakes. On the top of this box is placed an alarm clock. Now, when the alarm goes off in this position the garters always move a little, for the vibration is communicated to the wood and can be plainly felt with the finger-tips; but, when the clock is on the cloth-covered table close by and not in contact with the wood on which they lie, they never give a sign of having heard it.

When I lived on the island of Trinidad, I had a large collection of West Indian and South American serpents which it was necessary to feed on animals of many different species. It was always noticeable that neither boa, viper elaps, nor coluber ever gave the slightest heed to the voices of these, while at *sight* of the *moving* prey they manifested very evident signs of recognition. Snakes, as a rule, are very timid, and as I often had visitors at feeding time, it used to be necessary to warn them that any stirring about of arms or legs would be sure to delay the dinner; but no restriction was ever needed to be placed on conversation, except that the turning of the head

was forbidden—each had to talk straight to his front, no matter whom he addressed.

During the past four or five years I have hunted extensively over the woods of northern South America, from the Bay of Panama to the Delta of the Orinoco, often alone, sometimes with others. Now, when I had company it would be frequently necessary to call on their assistance in capturing some of the long, swift-running snakes. If one of these were discovered some distance off, resting close by a fallen tree, it was my method to go round to the other side of the old trunk and come up unseen, often within a yard of him. There I would shout directions to my friends, sometimes at the top of my voice, where to post themselves and where to head him off. This shouting never caused the snake to stir; but should I show the rim of my hat moving up even a hand's breadth over the intervening trunk, he would be off like a race-horse; for the eyes of a serpent, though dull to note form and color, are exceedingly quick to detect motion.

Now, it may be mentioned that snakes have no external ears, their heads being entirely covered, like the rest of the body with a tough and scaly skin. Yet in how far they may be able to detect sound waves in the air, as a general evidence of something unusual, with the delicate tip of the restless bifid tongue, is a subject that requires investigation; but that they can appreciate music in this or any other way is, as has been said above, absolutely untrue. How such an idea as that snakes are fond of music and milk ever gained credence among men calling themselves scientists only shows how few really scientific observers we have.

Men sometimes do strange things for the love of knowledge, and it was this love which caused me to live on such intimate terms with my scaly but graceful and gentle friends. I took them into my house to live with me. This was the best way to know them perfectly; and the more I knew them, the more I knew that they did not know me. I soon found out that neither cobras nor any other serpents can ever become capable of attachment, nor even distinguish one person from another, nor distinguish a man from any large animal, nor even

distinguish a man from a tree stump until he gives evidence of his life by motion.

During my stay in South Africa I had many cobras, all of which I captured myself, except those born in my collection. Now, cobra-hunting is a very dangerous kind of sport, and had I known of its perils otherwise than by experience it is probable that I never would have attempted it. The first two or three I caught safely, and nothing particular occurred to show that there was a special danger in taking *them* which did not equally exist in the capture of other deadly snakes. But I found out that in three important particulars of defense and attack the cobra differs from all his fellow-poisoners:

1. He rarely opens his mouth when striking, but actually gives a deadly blow without biting.
2. He bites deliberately when he is in a state of apparent death from muscular contortion, and will then hang on like a bulldog, the venom flowing all the time into the wounds in which his fangs are buried until he drops off at last from sheer exhaustion.
3. He can squirt the venom from his fangs into a person's eyes, and thus blind him for a time at least.

I had often heard of the "spuugh slang," or *spitting snake*, but looking at the thing from a *too human* point of view—as we are all, unfortunately, overmuch inclined to do when considering animals—I could not understand how a snake, not having fleshy lips and a bulky tongue, could be said *to spit* as we understand the word; and hence could no more believe in spitting snakes than I would in unicorns or fiery dragons. However, the result proved that oftentimes a story which on the face of it seems impossible has, after all, a certain fund of truth lying concealed somewhere at bottom.

One day, being alone in the bush, I saw a cobra banded with black and white. He was in an open glade, gliding about through the herbage, delaying a little perhaps for an opportunity to get at some birds that were chattering and hopping about on the branches of a thorny, yellow-blossomed acacia. The sun was blazing down fiercely on him as, with half-distended hood held close to the ground, he slowly passed through the leaves and flowers. For a few minutes I watched his move-

ments through my binocular glass; but, fearing he might notice me and escape into some hole, I picked up my six-foot hunting stick and rushed toward him, intending to press his head to the ground with it, and then take him by the neck with my hand. He saw me coming, and, like a valiant warrior that knew his power, he faced round and stood erect with expanded hood and quivering tongue ready to receive me. His bright black eyes sparkled with energetic defiance, and every fiber of his being was electrified with excitement. While I was yet ten feet away he struck toward me with such force that the impetus carried him flat to the ground. As I tried to get my stick across his neck he dodged it, and it came instead across the middle of his body. At this moment he was between me and the sun, with about five feet between his face and mine. I looked into his eyes and held him down firmly. His rage seemed redoubled. He leaned backward to make a more vigorous dash at me, and as he struck forward the mouth partially opened, and two tiny streams of venom shot from his fangs as from a syringe, one of them catching me on the face just beneath the eye. Had it gone a little higher up I should have been blinded for months, and perhaps had my sight permanently injured. This unexpected attack made me hasten the capture; so, getting his neck pressed down to the ground with the stick, I soon had him grasped in my hand just behind the head in such a way that he couldn't possibly turn to bite me—which he made every effort to do for some minutes afterward. Taking him home with much satisfaction, I made him thereafter my fellow-lodger. While living in his cage, I observed him many times squirt the venom from his fangs against the glass of its front. Thenceforth my doubts about spitting snakes were removed.

In order to understand how it is that he can eject the venom as high as a person's face—which we never hear of the viperine snakes doing—it is well to consider carefully the approximate difference in the fangs of the cobra and those of the rattler. Snakes of the class *Viperidæ* can, and do under certain circumstances, eject the venom somewhat similarly, but their methods of striking are more deliberate usually, and instead of the first and more copious discharge being thus lost, as is often the

case with the cobra, it is, on the contrary, injected into the veins of enemy or prey. This premature squirting out of the fluid in the cobra is not to be taken as a voluntary act. It has been mentioned above that he is so excitable that he will strike at a moving adversary long before he comes near enough to actually hit his object; and it is in striking thus from a distance that the poison-controlling muscles act as if he really struck something, and the distended gland gives way to the pressure, forcing the contents, which in other circumstances would have been injected into the flesh, to go instead in two thin streams through the air.

In regard to the manner in which the cobra strikes with effect without opening his mouth, it is necessary to state that while the fangs of the rattlesnake and other viperine snakes are laid horizontally back along the upper jaw when the mouth is closed and only erected when the mouth is widely open, it is not so in the cobra; but whether his mouth be open or shut, his fangs are always partially or wholly erect, and not in the true sense of the word reclining. Now, usually when he strikes at an adversary his mouth does not open as does the rattlesnakes, but he simply hits with his chin the point he aims at, so that, the mouth being still shut and the fangs during the act coming out over and slightly below the lower lip, these protruding fang-points penetrate the skin, while at the same instant the potent venom is squirted with force through these natural hypodermic syringes into the superficial punctures. Hence it is that on the bare legs of the natives this so-called "bite" is usually fatal, while the slight protection of trousers saves the European from danger.

As to the third peculiarity of this snake—viz., the fit of temporary lockjaw into which he is liable to fall and the terribly prolonged and real bite he can give when in that state—the account of an interesting adventure I once had will give a fitting illustration. It was a most wonderful exhibition of reptilian hysterics.

In the midst of a South African summer, when the springs and rivers are dried up, the snakes congregate in unusual numbers around the dams which are built by the colonists to store

up in the ravines for themselves and their cattle the drinking supply afforded during the rains by the mountain torrents. At one of these reservoirs in Currie's Kloof, near Grahamstown, I had secured several fine serpents, and was not surprised therefore when one afternoon, as I was sitting by an upper window, I saw a boy running from that direction toward the house, shouting as loud as he could bawl, "A snake, sir—a monster snake!"

I ran downstairs and found him, breathless and pale with excitement, at the door. The snake, he said, was fully twenty feet long. It had pursued him a little way through the bushes and then disappeared in a hole in the bank. "Aha!" thought I, "this must be the great Natal python I have heard so much about but never seen." With some doubts, nevertheless, about his being twenty feet long—for people usually imagine snakes which scare them to be much bigger than they really are—I took my snake-hunting stick and set off at once to make the capture. On arriving at the pond, which was overhung by poplar trees and nearly dried up, the boy led me across a long stretch of hardened, sunbaked mud to a point in the great earthen dam about twenty feet over from the water's edge, where there was a hole, the mouth of which he had carefully stopped up with a good-sized stone before coming to tell me. This I removed, and as the snake was not there ready to bolt out as I expected, I ran in the stick to dislodge him. This, however, had no effect. So, taking a piece of stout paling wire, I made with it a hook to the end of my snake stick. Running in this arrangement, I managed to catch it in his folds, a proceeding which he resented by slipping it off and by many angry hissings which sounded all the louder from being uttered in the confinement of his subterranean retreat. After several failures he was at last hauled out. "A cobra, by Jove!" said I, as he raised himself up erect with expanded hood on the hard mud expanse between me and the water. As his head when standing thus was fully eighteen inches high, it was no easy matter to press his neck to the ground so as to catch him safely with my hand. Without at all hurting him I made several attempts to get his neck down, and not without some nervousness, for

he might at any moment send a charge of venom into my face. This playing him with the stick to get him into proper position so aroused and alarmed him that at last, overcome by his own excitement, he suddenly collapsed, falling over on his side and lying there motionless, half on his back, with his mouth fixedly open and stiff as if in death. His whole body was rigidly contorted and as unbending as a dried stick. "Ah, you've killed him!" shouted the boy from the top of the dam, whither he had retreated for safety. However, as I had seen this manifestation before, I knew that it was only an hysterical fit. Warning the lad not to approach, I picked up the apparently lifeless snake by the tail-tip and flung him off from me to a distance of five or six feet. As soon as he touched the ground all his life was active again. Up he stood instantly with expanded hood as before, the black eyes glistening angrily and the forked tongue running out quiveringly from the closed mouth as if daring me to approach. A slight touch with the stick on the neck caused him to fall down in a second fit similar to that from which he had just recovered. There he lay again, to all appearance dead, with every muscle rigid and his jaws fixed in a partial gape as if sudden dissolution had prevented their closing. Seeing in this an opportunity of giving the boy a lesson against the danger of meddling with seemingly dead cobras, I called him down to my side. "Do you think that snake is dead?" said I.

"Yes," he replied, "I believe he is surely dead now; you must have given him his death wound getting him out of the hole."

"Well, my boy, I'll show you whether he is dead or not; and from what you will see, take warning that a bite from an apparently dead cobra like this is a thousand times worse than if he were to strike you perchance in the usual way as you pass through the bush."

So saying, I put the end of the stick into the stiff, gaping jaws. Instantly they closed on it like a vise until the fangs were buried in the wood. Then, lifting him up till his tail swung clear of the ground, I bade the boy count the time by his watch, to see how long he would retain his bulldog-like

grip. The body was gathered into unbending curves; but, as the minutes went by, these straightened out, commencing at the tail and advancing gradually upward to within three inches of the head. At last this too became limber, the jaws unloosened, and he dropped to the ground as the boy exclaimed: "Well, I'll be blamed! that bulldog snake held on for eight minutes and a half." As he lay now exhausted on the ground he put out his tongue at intervals, but never otherwise moved until I attempted to put the stick across his neck preparatory to taking him, when he stood up for fight as fresh as ever. However, I was nimble with the stick, and by its aid got my fingers round his throat just as he went into his third fit, and held his deadly jaws open again ready to close upon anything they should chance upon. Thus open-mouthed he remained as I carried him homeward, but recovered from his fit as he was placed in his cage.

The fears of the boy had quadrupled the animal's size, but still for a cobra he was large, being considerably over four feet in length. Having him now at home to practice on, I soon learned how to throw him into this state of temporary lockjaw, and instantly restore him again at pleasure. And besides this, I became certain that the ordinary wounds made by a cobra are nothing compared with his terrible bite when in this strange condition.

Among my collection I had at first six cobras. They used to eat frogs and toads, pursuing them around the room as a dog would a rat, seizing them by whatever part they could catch hold of, and swallowing them down whole and alive. After a time the family increased, for one Saturday night an old lady cobra surprised me by depositing on the dressing-table a number of living young ones about as thick as a large cigarette and seven inches long. In these little snakelings the instinct of self-defense was born; for, before they were a minute old, they stood up erect, ready to strike like their parents. They were provided with poison, too, but could not expand their hoods till they were a week older.

Dear, pretty, little venomous babies!—infant criminals of the reptile kind—they had no more knowledge of nor affection

for their mamma than if she were an old tree-root or something else inanimate lying in their way and troublesome to be climbed over. Nor would the mother take the slightest notice of her interesting family. Indeed, some of them she never saw at all. Most probably she didn't know that they were any relations of hers, or she would have shown them some little attention.

EVOLUTION AND NATURE STUDIES

The Serpentlike Sea-Saurians

By WILLIAM H. BALLOU

IN the latter part of the Mesozoic Age there was a great inland ocean, spreading over a large part of the present continent. The lands then above water were covered with a flora peculiar to the times, and were inhabited by some of the animals which later distinguished the Cenozoic age. In the seas were reptiles, fishes, and turtles of gigantic proportions, armed for offense or defense. There were also oyster-like bivalves, with enormous shells, three or four feet in diameter, the meat of which would have fed many people. In time, this great ocean, swarming with vigorous life, disappeared. Mountain ranges and plains gradually arose, casting forth the waters and leaving the monsters to die and bleach in Tertiary suns. As the waters remaining divided into smaller tracts, they gradually lost their saline stability. The stronger monsters gorged on the weaker tribes, until they, too, stranded on rising sand bars, or lost vitality and perished as the waters freshened. In imagination, we can picture the strongest, bereft of their food supply at last, and floundering in the shallow pools until all remaining mired or starved. It would be interesting to know how much of the great Cretaceous ocean forms a part, if any, of the vast oceans of to-day. If any part so survived, what became of the saurians carried forth into new ocean areas? Were they beaten on jagged rocks by powerful currents and destroyed, or did some of them escape only to perish in after ages? Water, as a rule, seeks its level; sometimes it is evaporated. If the Cretaceous ocean merely drained off into other areas before

rising lands, it is perhaps not unreasonable to suppose that the descendants of some of the saurians might have survived in the Atlantic or Pacific as they had existed in the Mesozoic Age. We can therefore only assume that the Cretaceous seas evaporated or gradually freshened until all the life they contained became extinct.

During the past twenty-five years explorers have collected tons of skeletons of the stranded sea-serpents, or better, perhaps, serpent-like sea-saurians. A sensational world has ever been on the lookout for sea-serpents. It is possible that such tendencies are inherited from a very remote ancestor, a primeval, man-like animal, whose curiosity was aroused by glimpses of some surviving pythonomorph.

Almost everywhere on the expanse of the Cretaceous ocean might have been seen the snake-like forms of the elasmosaurs, the heads arrow-shaped, upheld by swan-like necks, rising from ten to twenty feet above the surface and scanning the sea or air for prey or enemies. The prey located below, they dived; the enemy seen approaching, they swam away with incredible speed. A flock of them must have resembled the shipping of a harbor with tall masts yellowing in the sunlight. At the base of the long necks were elephantine bodies, and, behind, long, tapering tails. Forward and behind were two sets of paddles, perhaps terminating with webbed digits. With the forward paddles Cope thought that they might have seized prey; with all four paddles they swam. From thirty to sixty feet in length, they were well adapted to the deepest waters and to breast the waves of the seas. Like swans and Floridian snake-birds, they plunged their necks downward for prey, the body perhaps remaining on the surface as an anchor. Carnivorous, the elasmosaur ate what it could seize, and to-day, with its bones, are found the bones of its victims, usually fishes. Somewhat similar were the cimoliosaurs, even longer-necked at times, but with shorter and more powerful tails. Their paddles were long, and as swimmers they must have had few equals in speed. Smooth siliceous pebbles to the amount of a peck or two have been found in numerous instances associated with the remains of plesiosaurs of various kinds. They evi-

dently formed a part of the contents of their stomachs, but their use is not clear. But the real rulers of the Cretaceous ocean were the pythonomorphs, or mosasaurs, more like the typical serpents of to-day, and more entitled to be called sea-serpents.

The mosasaurs were more elongated and graceful in form. Their heads were large, flat, and conical, with the eyes directed laterally. The tails were long. They had fore and aft paddles with webbed digits, attached to the body with wide peduncles. With paddles and flattened tails they swam with ease and speed. Like snakes, they had four rows of formidable teeth on the roof of the mouth, not for mastication, but for seizing prey and holding it. Like snakes, they swallowed their prey entire, but, unlike snakes, they had not elastic throats. The jaw was, however, so articulated, jointed so far back between the ear and chin, ball-and-socket fashion, that the immense opening made up for the lack of expansibility of throat. The ends of the jaws were bound by flexible ligaments, permitting the passage of large fish or other prey. The mouth of the gullet was prolonged forward while swallowing, evidently being loose and baggy. The same habit pushed forward the glottis, or opening of the windpipe in front of the gullet. Like a serpent, the mosasaur hissed, owing to these formations. The tongue was long and forked, and when at rest was inclosed in a sheath beneath the windpipe and thrown out when the jaws were in motion. And thus, too, are the nearest living forms.

The mosasaurs attained great length, reaching from ten to fifty feet. They had long, projecting muzzles, somewhat like that of the blunt-nosed sturgeon of to-day, although the branches of the lower jaw were correspondingly massive. With such ramlike jaws the mosasaur possessed terrible powers of collision. They were scaled animals, and fragments of their hides and scales have been found in good condition of preservation.

The first mosasaur discovered was found by Major Drouin in 1776, on the banks of the river Meuse, near Maestricht, Germany. On this specimen was founded the genus *Mosasauros*, given it by Conybeare in 1822, although the skeleton was previously described by Cuvier in 1808. The inter-

esting history of the specimen, which created a profound sensation in the world of learning and became mixed up in the history of nations, is herewith reduced from Owen. The skull was founded in the quarries of St. Peter's Mount by M. Faujas Saint-Fond, Commissary for Sciences of the French Army of the North. In one of the galleries or subterraneous quarries in which the cretaceous stone of St. Peter's Mount was worked, about five hundred paces from the entrance and ninety feet below the surface, the quarrymen exposed part of the skull in a block of the stone which they were engaged in detaching. On this discovery they suspended work and went to inform Dr. Hofmann, surgeon of the forces of Maestricht, who for some years had been collecting fossils at this quarry, remunerating liberally the workmen for the discovery and preservation of them. Dr. Hofmann arrived at the spot and saw, with extreme pleasure, the indications of a magnificent specimen. He directed the operations of the men so that they worked out the block without injury to the skeleton, and he then with his own hands cleared away, by degrees, the yielding matrix, exposing the extraordinary jaws and teeth, which have been the subject of so many drawings, descriptions, and discussions. This fine specimen, which Hofmann had transported with so much satisfaction to his collection, soon, however, became a source of chagrin to him. Dr. Goddin, one of the canons of Maestricht, who owned the surface of the soil beneath which was the quarry whence the fossil had been obtained, when the fame of the specimen reached his ears, pleaded certain feudal rights in support of his claim to it. Hofmann resisted, and the canon went to law. The whole chapter supported their reverend brother, and the decree ultimately went against the poor surgeon, who lost both his specimen and his money, for he was made to pay the costs of the action. The Canon Goddin, leaving all remorse to the judges who had pronounced the iniquitous sentence, became the happy and contented possessor of this unique example of its kind. But justice, though tardy, comes at last. When the town was bombarded by the French, directions were given to spare the suburb where the famous fossil reposed. After the capitulation, the grenadiers discovered, seized, and bore off

the specimen in triumph to the commissarial residence. The excellent soldiers always knew how to appreciate and respect the monuments of art and science. The mosasaur was transplanted and still remains in the Museum of the Garden of Plants, Paris, and is the subject of more literature than any extinct animal.

Remains of the mosasaurs were first discovered in England in 1833, at Lewes. In America, mosasaurs were first found in the cretaceous beds at Great Bend, Missouri, about the year 1820, by Major O'Fallon, Indian agent. He found a fine specimen, and took it to his home in St. Louis. Dr. Goldfuss first described it in 1843, with accompanying plates, the skeleton having been taken to Germany by Prince Maximilian. He defined the parietal and jugal arches, pterygoids and vomers, the position of the quadrate, and the presence of the sclerotic plates. Since that time our knowledge of the mosasaurs has been largely increased by the explorations and efforts of Cope, Marsh, Dollo, Owen, Leidy, Williston, Baur, Merriam, Gaudry, Gervais, and others. Cope, perhaps, defined the largest number of species. March defined the stapes, columella, transverse and hyoid, and the presence of hind limbs. Dollo has materially increased the data of mosasaurs and has added four new genera. Baur gave the first complete description of the skull of a species of *Platecarpus*. Williston and Case first described the vertebral column and extremities and the general form of mosasaurs. The former has contributed most to our knowledge of mosasaurs in the Kansas Cretaceous, and made the first correct restoration, which is made one of the bases of this paper.

Professor S. W. Williston, University of Kansas, because of his perfected restorations and wide studies of the sea-serpent-like saurians, the mosasaurs and other marine saurians, must rank as the highest authority. It is largely on his material that it is possible to present something like a complete view of the gigantic monsters that swam the Cretaceous seas and gave origin to our notions of mythical sea-serpents. Kansas is the great center of the Cretaceous time of occupation, and it is within its borders that the largest number of species and genera of sea-serpents have been discovered. It is natural, perhaps,

that, living in the vicinity of the most prolific Cretaceous remains, Professor Williston should be better able than scientists more remote to complete our knowledge of marine saurians.

There are three groups of the serpentlike sea-saurians—the ichthyosaurs, plesiosaurs, and mosasaurs. Of the mosasaurs, Kansas has produced the largest number of species, twelve of which have been satisfactorily described. New Jersey, Alabama, Carolina, and Mississippi have perhaps ten valid species. Dakota has favored us with three species. It is estimated that of fifty species attributed to North America, about twenty-five or thirty will be distinguished as distinct. It is expected that in the Fort Pierre formation of the Dakota region other species will be found, as it has been but imperfectly explored. Europe has about a dozen species, and New Zealand several more. Probably only about forty species of twice as many alleged to have been discovered in the world will stand the test of critical examination.

Of plesiosaurs, America has produced about ten and the Old World many more species that will stand. Many species of ichthyosaurs are recorded from Europe, India, Africa, Australia, New Zealand, and the arctic regions, and one or two in America, the toothless *Baptanodon* from the Jurassic of Wyoming being the type. All three groups had paddles with webbed digits, but none had claws. Williston thinks that the ancestors of the mosasaurs were land lizards. Dollo thinks that the ancestors were the peculiar group of lizards which appeared in the commencement of the Cretaceous known as *Dolichosauria*. Baur would derive the mosasaurs from even more specialized lizards, and believes that their relationship is very close to the monitors of the present day.

The ichthyosaurs are thought by Cope to be derived from *Homæosaurus* (beakless lizards) of the Jurassic; and these from the *Palæohatteria* (ancient hatteria), a rhynchocephalian (snout-head) which flourished as early as Permian times; and these from the *Labiosaurus*, an ancestor below the Carboniferous in the Palæozoic Age; from which also sprang the lizardlike saurians, the dimetrodons (*Otocælius*), which gave origin to the turtles (*Testudinata*). Some members of the group to which

the plesiosaurs belong were land animals, and hence the origin of the whole group is clearly from land species. It is not now presumed that the marine saurians had much power of progression on land, but they may have climbed on to the beaches to lay their eggs. It is further presumed by Morris that in later times the eggs of saurians were devoured by other animals, contributing to the extinction of all saurians.

Three species of representative genera of Kansas mosasaurs have been restored by Williston from material in the University of Kansas.

Clidastes velox (Marsh) is a typical mosasaur, the perfected skeleton of which is twelve feet in length. *Pumilus*, of the same genus, is given as six feet in length, which would rank it as perhaps the smallest mosasaurian. The clidastes of Kansas had short, powerful propelling tails, which would indicate a lesser speed than that of their longer-tailed contemporaries. The clidastes had small hind limbs, showing further deficiency in speed. The animals were slender, with short heads. The vertebræ were firm, closely articulated with the best system of interlocking of any of the mosasaurs. The limbs were flexible and strong, with closely articulating bones and fully developed tarsus and carpus. The aggregate of these characters indicates the most snake-like form and method of progression through water of all the mosasaurs. The genus *Clidastes* was founded by Cope in 1869, but may ultimately give way to the genus *Mosasaurus* of Conybeare. Cope's views of clidastes conclude that the animals were not as large as those of the genus *Liodon* (Owen), but more elegant and flexible, with an additional pair of articulations at either end of each vertebra—the zygosphenes—to prevent dislocation by contortions. A larger and still more elegant species was *Clidastes tortor* (Cope), with lithe movements which enabled it to capture fish by means of its knife-shaped teeth, which were very numerous. Tortor was very slender, with a long and lance-shaped head. It was upward of twenty feet in length, with a head two feet and a half long, the vertebral column elongate and the head narrow and pointed.

The second-type mosasaur perfected by Williston is *Plate-*
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carpus coryphæus (Cope). Its special characteristics are a short muzzle, slender vertebræ, and an imperfect interlocking zygosphenes. The hind paddles are smaller than those forward, but thought to have been more powerful propelling functions than those possessed by other genera. A type skeleton measures fourteen feet, and may have been a young animal. The teeth were very curved and pointed, and formed effective weapons. The neural spines, not closely connected, indicate flexibility. The general characters suggest a powerful predaceous sea-serpent. The genus was founded by Cope in 1869; it has a wide distribution, and seven or eight species belong to it.

Tylosaurus proriger (Cope) is the third of Williston's type Kansas specimens perfected in restoration. It is considered the most specialized of the mosasaurs. The skeleton in hand is twenty-three feet in length, and shows a wholly cartilaginous carpus and tarsus, more elongated digits, and a greater number of phalanges than possessed by any other genus, the result of long aquatic habits. The hind paddles are the largest, and the fifth digit has undergone but little reduction, indicating characters of a very primitive rank. The vertebræ are more flexible than in other genera, but they are relatively smaller and not at all strong. The skull is more elongated anteriorly. In the same genus was a much larger species, *T. dyspelor* (Cope), which was one of the most formidable of the mosasaurs. Another perfected sea-serpent of terrible powers was *Mosasaurus horridus* (Williston), which had a ram nose, and evidently battered its foes when it could get at them. Williston's perfect skull from Dakota enabled him to correct many errors in vogue. The new genus *Brachysaurus*, formed by Williston, contains one species defined by him—*Overtoni*, from Dakota. It had a stout, very broad head, stout jaws and teeth, and stout, broad paddles. In appearance it suggests a terrible fighter, unadapted to rapid pursuit or flight.

Williston thinks that the food of the sea-serpent-like saurians must have consisted of fishes of moderate size, with occasional victims of their own kind. He says: "While the flexibility and loose union of the jaws undoubtedly permitted animals of considerable size to be swallowed, the structure of the thoracic

girdle would not have permitted any such feats of deglutition of which the python and boa are capable. The animals must have been practically helpless on land. They were not sufficiently serpentine to move about without the aid of limbs, and these were not at all fitted for land locomotion. They lived in open seas, often remote from the shores. Their pugnacity is amply indicated by the many scars and injuries they received, probably from others of their own kind."

Over the water were the flying saurians of formidable proportions, and which may have been both pursued and pursuer, according to size of mosasaur and pterosaur. The pterosaur had a wing expanse of eighteen to nineteen feet, as instanced in *Ornithostoma umbrosum* (Cope), the largest in size, and *O. ingens* (Marsh). The pterosaurs flew with leathery wings over the waves, plunging to seize unwary fishes or perhaps to be seized by mosasaurs, or soaring at a safe distance while watching the combats of swimming saurians. At nightfall they trooped along the shores, at last to suspend themselves to the cliffs by the claws of their wing limbs.

Prof. O. C. Marsh, of Yale College, was the first naturalist to discover sufficient of the missing parts of skeletons to determine that marine saurians propelled themselves with paddles rather than flippers. As to the scales and skin found perfectly preserved by Snow, they do not differ materially from those of the Old World lizards, the monitors, existing to-day. The paddles, skin, and scales are very delicate functions, and it is remarkable that they should have been preserved through millions of years. Williston says of the paddles: "The specimen figured by Chancellor F. H. Snow, of the University of Kansas, has been thoroughly cleaned from the matrix, enabling an accurate drawing to be made, also a photographic reproduction as it lies on a chalk slab. The parts concealed beneath the ribs and vertebræ have been carefully laid bare from the opposite side and their position shown. The position of the paddle is a natural one, and the fact is of interest as showing the general expansion and curvature of the digits." The limb is very flexible, with considerable space between the bones, which were but partly filled out with cartilage, and must have had very free

articulations. The remains of the skin were found between the bones, indicating a thin, pliable membrane, and extending fully between the fingers to their tips. Small scute-like scales extended as far as the metacarpals. The fifth finger is long. The paddles are slenderer, more flexible, and relatively longer than in other genera, which, with other characteristics, would show that *Tylosaurus* was the least lizard-like of the *Pythonomorpha* (Cope.) As to the structure of the hind paddle, it is of interest in having five functional toes, although Williston thinks that the fifth toe was undergoing reduction, and that the first toe was not as long as in the front paddle. He concedes five toes to the hind paddle of *Platecarpus* (Cope), but doubts, in the absence of a complete skeleton, if *Clidastes* had more than four functional toes, as in *Mosasaurus*. Upon this character, together with the absence of a sternum, he has established two families, *Tylosauridae* and *Mosasauridae* and the two typical genera, representing the extremes of development of this order of reptiles.

In this connection it is interesting to note the views of certain scientific men of the times in which these gigantic sea-serpents existed.

The views of Prof. Frank C. Baker, curator of the Chicago Academy of Sciences, follow: "At the time the great sea-lizards lived, North America was shaped something like the following: It included all of Northeastern Canada and Nova Scotia; the shore line was the same as at present as far as New York, where it was deflected to the southwest and went through the western part of New Jersey, Delaware and Maryland, and then went directly across the middle of Alabama, north again to the mouth of the Ohio River where it meets the Mississippi River, then north into Iowa, and finally north and northwest across the United States and British America. Herein existed a great inland sea in which the sea-lizards lived. The past history of the world tells us that thousands of animals of gigantic size lived in the ancient seas. In old Jurassic and Cretaceous times we had such queer combinations as *Ichthyosaurus* (or fish lizard) and *Plesiosaurus*. Not only were reptiles found in the water; they flew about in air. The latter were represented by

the *Rhamphorhynchus*, a bird-like reptile which had wings like a bat, teeth like an alligator, and the tail of a lizard. In the Connecticut Valley we find the footprints of huge reptiles in the red sandstones whose feet measured from those of a few inches in length to the footprints of the gigantic *Otozoum*, which measured twenty-two inches in length, having a step of some five feet."

An immense amount of literature has been printed on the subject of the Cretaceous formation and its inhabitants. Very recently there have been immense advances made in the restoration of species existing in Cretaceous times. This article, therefore, is in the nature of scientific news, and a separation of facts from a mass of errors. In looking over the works of others, one is impressed by the many mistakes made by specialists, owing to imperfect skeletons and collections. A careful study of these errors has been made in the light of the latest skeletons reconstructed and the latest discoveries made.

The Kansas University, in securing three perfect type specimens of three genera of mosasaurs, presents three important items of scientific news. These skeletons teach us the errors and pitfalls into which specialists have fallen who lacked certain parts of the skeletons and filled out the gaps by aid of the imagination. Only recently the country was startled by the alleged discovery of the skeleton of a supposed reptile, having a length of two hundred and fifty feet. The newspapers gave startling pictures of the supposed appearance of this reptile while on earth. Professor Williston naturally wanted to see this gigantic animal, the largest ever discovered. On examination of its bones he saw at once that it was a whale. It can safely be asserted that no animal ever attained a length of two hundred and fifty feet. Perhaps as serious errors as this may be found in many of our text-books and monographs, due, of course, to former incomplete skeletons. The appearances of the skulls, the jaws, and the teeth have been painfully distorted in like publications and on charts in class rooms, and demand a thorough overhauling before our youth are further taught errors. With late complete discoveries, we have now exact appearances of the functions of the heads from which we can

derive correct views. It was formerly thought that the eyes of the mosasaurs were directed upwardly; to-day it is known that they were directed laterally, as in living lizards. It has been supposed that mosasaurs attained a length of one hundred feet; no skeleton has been found which would show a length of more than fifty feet. The great majority of skeletons taken range from sixteen to twenty feet in length. It was formerly supposed that mosasaurs had the powers of running, springing, and climbing on land; it is now known that they were wholly confined to salt water, and merely climbed the beaches in order to lay eggs. It is not an easy step from mosasaurs to modern snakes; it is an utter impossibility. Professor Marsh formerly thought, and it has been taught in the class rooms, that the bodies of mosasaurs had bony scales; they had skins, and were scaled throughout like modern lizards and snakes. The *Rhamphorynchus* has been held up to us as a "lizard-like bird"; it was no more like a bird than is a bat; it was a bird-like reptile. These suggestions certainly point to the necessity of a revision of the text-books and charts in use in class rooms, which in many instances should become obsolete because of perfected restorations.

Specialists regard the marine saurians as having existed some millions of years ago. They conclude that these animals had at least a million years of existence in various forms. While it may be venturing into the domain of the encyclopædia to state the causes of these conclusions, a word here may not be out of place. The Cretaceous formation, in which the marine saurians are found, is of chalk, green sands, etc., and ranges in thickness from 10,000 to 20,000 feet or more. It existed in the last part of the Mesozoic realm. From the thickness and position in geological strata scientists deduce its age and place in Nature. As the remains of marine saurians are found only in the Cretaceous deposits, specialists speak of them as existing several million years ago. At that time were numerous fishes, birds, reptiles, and plants.

EVOLUTION AND NATURE STUDIES

The Forms of Water

From Notes and Photographs by W. A. BENTLEY

THE most remarkable thing about water, perhaps, is the bulk of it. Eight elevenths of the surface of the globe is covered by oceans; but much of the remainder, the land-area, is hidden from view and use by polar ice, or by the seas, ponds, lakes and rivers, which are so numerous that their absence from any spacious district makes that notable as a desert. Between the valleys of these lakes and rivers rise mountains, sometimes to heights that daunt us when we try to climb them; yet if all the highlands were leveled and shoveled into the sea until the globe was perfectly smooth, water would clothe it like a glassy shell two miles thick. This would seem sufficiently impressive, but it must be remembered that an enormous amount of other water is present in the world which we do not see at all, so perfect are its disguises. It is seeping in a million channels through the soil beneath our feet, lies in inexhaustible reservoirs deep down among the rocks, is included in the structure of the stone itself, and constitutes the greater part of the substance of all animals and plants,—in some cases more than 99 per cent of their bodies. Lastly, the atmosphere carries billions of tons of water, which it is constantly taking up and throwing down,—an exchange which not only involves the continuance of this planet as a habitable place, but a series of most interesting processes whose results are no less important because they are among the most familiar of everyday experiences.

In order to understand them, and to solve the mystery which seems to lie in the rising mist and gathering cloud, the sudden appearance of dew or frost, the incident of a gentle rain followed

by hurtling hail, the amazing alteration of the sparkle and movement of a brook into a dull mass of ice, and many other curious phenomena, we must know something of the composition and characteristics of both water and air, and of the effect upon them of heat and cold.

If the reader will turn back to the section of "Physical Geôgraphy" in the present volume, he will learn, with much useful detail, that water is the result of a mixture of oxygen and hydrogen gases; and that the atmosphere is another gas composed for the most part of oxygen and nitrogen.

Water and air are everywhere and incessantly in contact, and are affecting each other through the co-responding processes of evaporation and precipitation—taking up and throwing down.

HOW THE AIR RECEIVES ITS MOISTURE

As practically no object in or upon the surface of the earth is entirely dry, it may be said that everything gives off vapor varying in amount with the water it contains, with the comparative dryness of the air which touches it, and with the temperature,—the last condition being of great importance.

The molecules—but wait!—perhaps you have not a clear idea of molecules?

A molecule is the smallest part of any substance into which it may be divided without destroying its chemical character. Molecules have a real existence, although so invisibly minute that they cannot be measured, but only estimated mathematically; and it is believed that hundreds of millions side by side would not span the breadth of one's little-finger nail.

Now these molecules are never still. On the contrary, they are flying hither and yon with inconceivable rapidity, and hitting one another billions of times a second. The real basis of this explosive condition, which wrenches the molecules apart so violently, is probably electrical, but however that may be the commotion and speed increase with the amount of heat the thing has. Nothing but absolute cold would keep them quiet, and we do not know of absolute cold in this world outside of a laboratory experiment. When, then, we say that all objects are



DEW ON SPIDER'S-WEB, AND ON PLANTS.

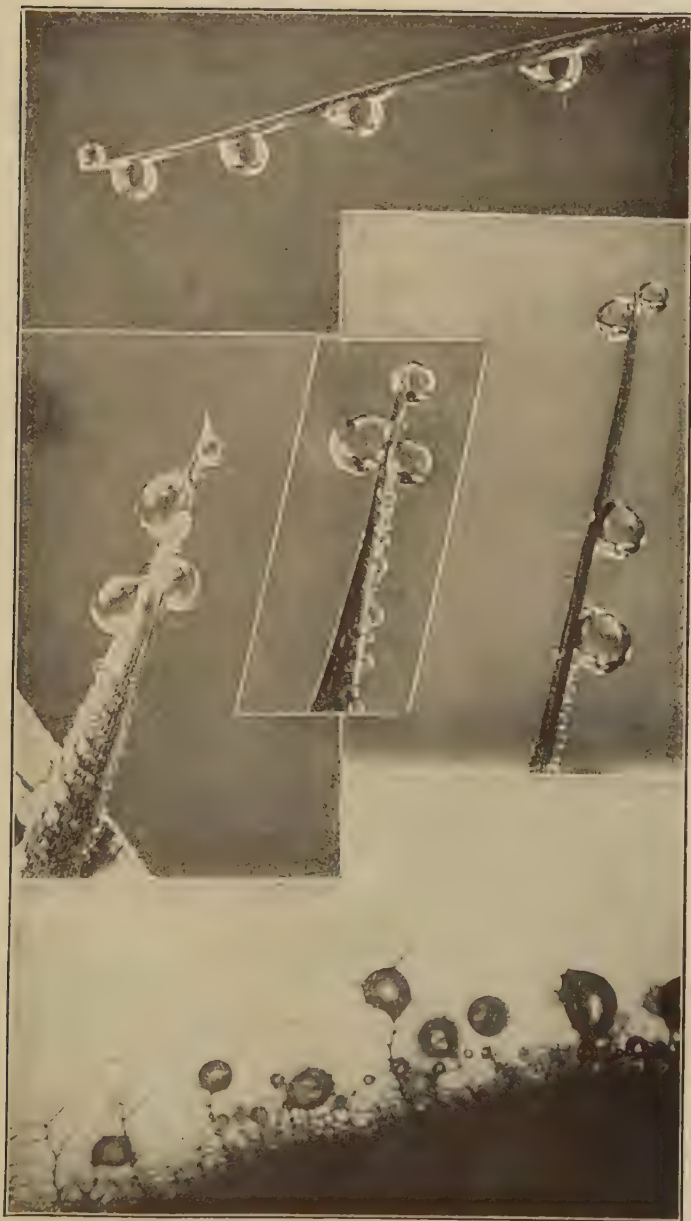
throwing off vapor, we mean that the molecules of water are continually jumping off into the lighter, thinner gas which we call air, and are being caught and entangled among the air-molecules, in the spaces between them; and of course a body of free water, such as a lake, supplies more vapor than anything else. When air is warmed by the heat of the sun, or by that radiated, or given out, by the earth, it expands—that is to say, the molecules separate more than when it is colder. This gives more room for the entrance between them of the molecules of water which compose vapor; or, in other words, warm air can soak up more water than the more compact cold air. If the air were still, as it is in a bottle partly full of liquid, or in a wet cave, it would soon become saturated, that is get as full of water as it would hold; but this rarely happens over any large surface out-of-doors, because the atmosphere is in constant motion; there again heat plays a part, for the expanded warm air is lighter than the contracted dry air, and continually rises, while the heavier dry air sinks down to take its place and receive its quota of water, or its humidity, as the weather-experts say, then rise in its turn. This and other actions produce winds which blow the air about, and enable every part of the atmosphere to become more or less loaded with moisture.

These particulars have been given at such length because nearly all the forms of water which we are about to consider depend upon the fact that the air carries it in a greater or less quantity at all times and places, and that heat and cold affect this mixture, or humidity, very strikingly. Heated air not only absorbs moisture rapidly but retains it to the point of saturation. We suffer on a still muggy summer day because the heated air is so wet that it will no longer take up the moisture which our skin seeks to throw off; and, we are refreshed in a dry breeze because it favors evaporation—always a cooling process.

Now this holding of the water-vapor means that the heat in the air is sufficient to keep its molecules dancing too rapidly to cling together when they touch; but when the air becomes cool, as at night, by a chilling wind, or in winter, they lose speed until they are able to grasp one another, as it were, and collect together,

finally coalescing into visible drops. If the cooling goes on the air contracts and actually squeezes out its moisture as would a pressed sponge, and then begin the various manifestations of water which we call fog, cloud, dew, rain, hail, hoar-frost, snow, ice, and so on. Indeed, it may in truth be said that the weather, so far as it affects our comfort, is merely a matter of the proportion of water in the air about us, and how it is behaving under the influence of heat or cold. When the atmosphere is comparatively dry, even though the sun's rays feel very hot, we are fairly comfortable, because the dry and porous air constantly absorbs from the open pores of our skin the moisture which they pour out and which carries with it the too great heat of our blood; if a breeze fans our faces it the more rapidly sweeps away the perspiration. When we are surrounded by a moisture-laden *warm* air, however, such an escape of uncomfortable heat is prevented, because the air cannot take up, or will absorb but slowly, our perspiration.

In cold weather our comfort also depends upon the degree of moisture in the air, but according to a different rule. Cold air is not necessarily dry air: but when it happens that cold air *is* also dry, it is a very poor conductor of heat,—that is, it is slow to receive and store heat. Consequently when the winter air is dry, as is usual in the interior of continents, it absorbs the heat from our bodies so slowly that we do not at once feel the loss; whereas any moisture in cold air sponges away our heat so rapidly, especially when the wind blows, that we are instantly chilled. Water is a quick heat conductor, and it is really the *moisture* in the air which gets hot or cold rather than the air itself, the sun's rays passing through dry air with very little warming effect. This is apparent to persons rising high in balloons, who find themselves in intense cold even when the summer sun is shining; and it accounts for the perpetual snow and ice on lofty mountaintops. The expansion and consequent thinning of the air as it rises (see page 275), assists in this result, but is only a part of the cause of the cold. On the high western plains a man standing in the noonday sunshine will be almost scorched by the intensity of its rays; yet if he sits a few minutes in the shade of a rock he will want to put on his coat.



DEWDROPS ON GRASS, AND ON A MULLEIN LEAF,

PEARLS OF DEW

Go out early on a summer morning, after a calm clear night, and your eye is surprised and imagination entranced by the beauty of the world. In the warm morning light the fields stretch away gray-green under a gauze of silver, and where the level rays of the rising sun strike along the sward between the trees they glint from a million diamonds sown broadcast over Nature's gown. Tiny drops tremble upon the spears of the grass, stud the flowers with needless adornment, glisten like strings of waxen beads along every vagrant thread of gossamer, and turn the curving tufts of fern into plumes snowy as those of Navarre. It seems the effect of some artistic magic, and one hesitates to think of it in a scientific way, or to explain what seems given to us only to enjoy.

“See how the orient dew,
Shed from the bosom of the morn
Into the blowing roses,
(Yet careless of its mansion new
For the clear region where 't was born)
Round in itself encloses,
And in its little globe's extent
Frames, as it can, its native element.”

Last night the air was heavy with moisture, and felt damp when we reluctantly left the porch and retired to bed. We fell asleep undisturbed by wind, and while we slumbered the quiet air, cooling slowly, let its particles of moisture gather in tiny drops, which ever drew others to themselves and clung in groups to every exposed object. Whatever was under a roof, even in an open shed, or shielded by dense foliage, collected no dew from the overladen air, because it remained warm; the shelters kept what was beneath them from cooling sufficiently to cause the molecules of vapor which touched them to collect into globules of water, or condense, as this change from a gas to a liquid under the influence of cold is called. The clouds retain the heat of the earth in a similar way on dark nights, and therefore prevent the formation of dew generally, and windy nights are unfavorable because they waft the water particles within the

air along so swiftly that they cannot attach themselves to anything. We speak commonly of the dewfall,—“Whither midst falling dew,” exclaims Bryant in his poem to a water-fowl—but a truer expression would be “gathering.” Yet it is said that sometimes the dew may actually be seen falling like a fine mist, and in some parts of the world it appears so copiously in summer as to greatly refresh the vegetation which would otherwise perhaps perish through lack of rain.

“The dew upon the tender crops,
Like pearls white and round,
Or like to melted silver drops,
Refreshes all the ground.”

says an old ballad.

In this case, of course, most of the deposit received from the air is absorbed by the thirsty plants; but ordinarily the first rays of the sun turn the tiny drops back into vapor, and often on a warm morning, as after a summer shower, you may see the dew rising in wisps of steam, and returning to the source whence it came.

If the landscape at dawn, “silvered o’er” with the diamond dust of the night’s gift, is beautiful in its breadth, admirable also is many a minute bit of loveliness to be seen as one strolls ahead of the sun along the garden path or across the shining meadow.

You will note first that some plants are more copiously bedewed than others; these are those which are quickest to lose their heat and moisture, and an important service in the dew is to cover and close their pores and so conserve the moisture which they so greatly need. Grass is such a plant, and nowhere does the dew lie so heavy as on its blades.

“Dewdrops formed upon the grass blades,” remarks Jean Thompson, “are arranged in a truly wonderful symmetrical fashion, and one marvels at the orderly arrangement. Frequently one large dewdrop, clear as a diamond, is deposited upon the very tip of the little grass blade, sometimes two and even three large drops are held in suspension thus, while upon the extreme sharp edge of one or both sides of the blade a collection of small, bead-like drops cling in orderly, precise fashion, strung from tip to root of the grass blade. A blunted or broken blade of grass collects no dew, or very little. When the large dewdrop

perched upon the tip of the grass blade decides to fall it descends rather slowly at first, following the extreme edge of the blade in its course, and thus meets and collects all the other dewdrops which it encounters strung along the edge of the blade, until forming at last one heavy drop it suddenly falls to earth, where it is instantly absorbed, and goes to give life and strength to the roots of the plant.

This disposition of the water jewels to attach themselves to points along the edges of leaves is most exquisitely shown, perhaps, on a strawberry leaf, where every serration is diamond-tipped. Similarly leaves and stems with a hairy or velvety surface are frosted in tiny drops, each mounted upon a trembling standard and rippling with prismatic reflections. Imagine the fairy beauty of a dandelion seed-head, or a tuft of thistledown, so bedecked,—but the effort is needless, for you may see hundreds of them as you stray through the meadows “dew’d with showery drops,” as Tennyson writes.

Over such grass are stretched the broadly woven nets of spiders, silken snares now become a pearly lace of extreme delicacy. The glutinous threads give easy attachment to the molecules, and they gather on them until every strand is formed into a dewy rosary. Each globule is a magnifying glass and worth getting down upon your knees to look through: it is also a mirror, on whose curved surface is painted a miniature of the landscape in lines so fine that one needs a microscope to fully appreciate its delicate beauty. There is an Eastern saying that in a drop of dew the whole universe may be reflected.

When, towards morning after a dewy night, the temperature drops near to the freezing point, the dew freezes, and we have hoar frost.

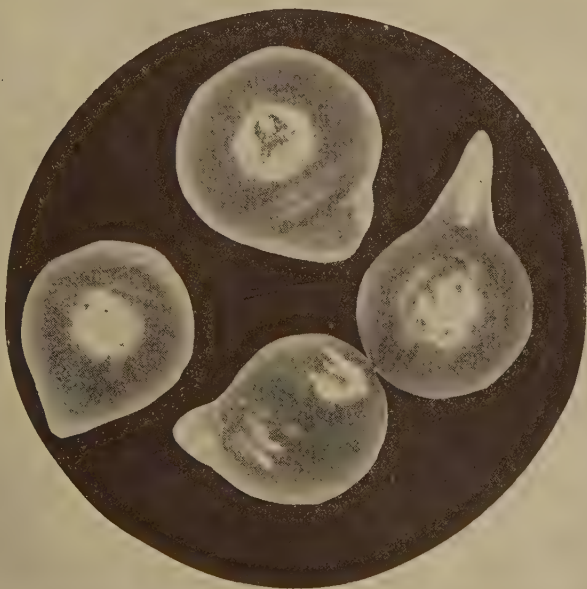
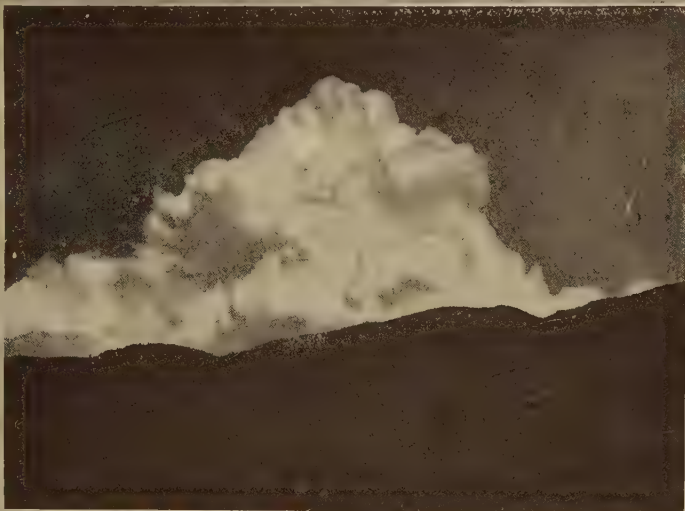
THE BENEFICENT CLOUDS

Clouds may be said to be dew formed in the air instead of on the surface of the earth. When the air near the ground is sufficiently cool to cause its contained dampness to form into very fine drops, but the temperature and other conditions do not favor these particles of water (most of which, in cities, are formed

about atoms of dust or smoke) uniting into large drops, then we have an air more or less densely filled with moisture and call it a mist or fog. When it rests on the ground, or just above it, it is usually due to the coldness of the ground or water over which it lies; and after a time is dissipated, either by the warmth of the sun which dissolves it into clear air again, or by increase of cold which causes it to fall as rain, or by wind which carries it aloft and away.

Now it is a frequent experience in climbing high mountains to find oneself enveloped in mist as he nears the top, and he knows that persons looking up from the base of the mountain call it a cloud. Perhaps when he gets a little higher he will be able to gaze down upon a billowy expanse of vapor which looks as though it were boiling, and which reflects the light of the clear sky like a waste of snow. Presently he sees it clear away and reveal the earth glistening with the rain, or whitened by the snow which has fallen from his chilling fog. The situation is easily explained. The moisture in the atmosphere about the mountain top has been cooled by contact with its cold rocks and snow-banks. The summits of lofty ranges are nurseries of clouds which may enwrap them for days together, or may drift away in long processions, or stream out upon the wind like banners, as has been described on page 276.

But aerial fogs, or "clouds" may form in the air at any height, and quite independently of earth or its mountains, wherever a current or layer of cold air causes condensation, and may assume forms, under the influence of wind and temperature, which often look extremely curious, and seem endlessly diversified, yet may be classified in three groups, mainly according to the height of their position. Land or sea fogs, scud-clouds, and the low cumulus and nimbus, or summer rain-cloud, are in a group low in altitude. Higher floats the "intermediate" group, containing those termed cumulo-stratus (the thunder cloud) the cirro-cumulus or cap cloud, and the low stratus, which takes its name from its long, thin and level appearance. These intermediate clouds are the largest rain-producers, and the grandeur of one of them, "a thunder head," is portrayed in one of the accompanying photographs.



THUNDER-CLOUD.

HAILSTONES.

The wispy, frayed-out cirris or snow-cloud, the cirro-stratus and the high cirro-cumulus, go to form some of the higher clouds. None among these is so lofty or so interesting as the cirris, for that flies in a sky so cold that the particles of mist are crystallized into spicules of ice, and blown out like a loose feather or the snow-dust swept from the drifts by a winter gale. Many of the cirris clouds are formed above heavy storms: and it is most interesting to watch a large thunder or shower cloud push upward to cirris heights, then tassel out and transform itself into the fuzzy cirris crest, which broadens in all directions like a mushroom.

It is at these wintry heights that halos, parahelia, and similar appearances in the sky occur.

RAIN AND ITS SERVICES

Rain is the moisture in the air condensed or crystallized in the free air, and deposited upon the earth in the form of liquid drops of various sizes. It is only in part a product of the clouds and of liquid condensation. Much of it, and especially the larger drops, is due mainly to the melting of snow on its way to the earth. That which comes from the clouds is due to the condensation and merging of the specks of liquid water of which the clouds are composed. Raindrops vary greatly in size, often within the same storm, from microscopic droplets, such as often fall from low clouds and fog, up to monster drops, a fifth of an inch in diameter, seen in newly forming thunder showers.

A study of the raindrops of different storms, as they come directly from the sky, is full of interest. Let them fall into fine flour, previously smoothed over by drawing a straight-edge across it, and they can be immediately studied and roughly measured; or let them remain within the flour until the pellets of dough formed by each one is dry, and then remove the latter and measure them, or preserve and label them for future study. The pellets will be found to be approximately of the same size as the rain drops that made them.

The raindrops tell a most interesting story. Their dimensions, in connection with certain other factors, frequently indicate their origin and previous condition. whether as snow or

rain, the height from which they fell, and other facts. If they fall scatteringly, and of nearly uniform or medium size, the probabilities are that they were formed from the melting of granular snow pellets. If of large size they surely fell from a lofty height, and passed through a great thickness of clouds.

Tiny raindrops most commonly emanate from low foggy clouds, but also in some cases from a thin stratum of high cloud. Raindrops originating as snow, are first granular, and afterward enlarge by overtaking and merging with smaller drops and cloud particles, on their way to the earth. The large drops may continue to grow by overtaking smaller ones, even after they leave the clouds, but they also lose a little thereafter to the relatively dry lower air, which absorbs a trifle from each drop as it hurries downward.

Rain fills an all-important part in nature. It occurs almost everywhere, and performs the major part in supplying the earth's vegetation and animals with the necessary moisture. It is hence not so much what it is, or how and where it forms, as what it does, that endows the rainfall with its greatest interest and import in the economy of nature. Rain aids in a most marvelous degree, both directly and indirectly, in changing and beautifying its aspects and moods. We might almost call the trees and flowers forms of water, or rather forms of the rain, so wholly are they due to it, and so largely are each and every one of them composed of water.

We have but to go to desert regions, where rain is absent, and to note the brown barren aspect, the treeless hills and mountains, the sandy, dust-covered, riverless plains, practically devoid of life of any kind, and compare these regions and conditions with the verdant herbage and forest where showers are plentiful and the land is threaded with streams and teeming with life of all kinds, to realize how profoundly nature's aspect and state is modified by the presence or absence of rain.

One of the most wonderful and surely not least important of its many rôles is that of earth-sculptor. The floods it poured down have been ceaselessly at this Titanic task through all the ages, chiselling or tearing the rocks apart, particle by particle. They have carved mountains and hills and valleys out of up-

heaved table lands and up-thrown fault-blocks, and are still striving to raze the hills and mountains to their base level.

Go out after a rainfall, among the dripping trees and revived plants and grasses, and wend your way to the nearest brooks on the hillside, note how swollen they are and how they foam along turbid and muddy with sediment. Every grain of soil and sand and rock carried along by the brook, has been torn by water from the rocks of some hillside, mountain or tableland. It seems an almost infinitely slow task, this razing of the hills and mountains, yet it is a no less sure and gigantic one. It is doubtless true that even now considerable areas among the mountains and plateaus of the globe would be much too elevated and cold for habitation and cultivation, had not the rain worked ceaselessly during past years to wear them down to their present level, and in so doing pulverize and dissolve the rocks into soil.

Rain is of interest not only in itself, but in its transformations and the varied phenomena due to it. The lovely rainbow, and the so-called ice storms, are but some of its manifestations. Who has not admired and enjoyed the glories of an ice storm, when the rain freezes upon everything as it falls, and encases every object out of doors in a gleaming coat of glassy mail? No fairyland of the fancy could be nearly as beautiful as is nature at such a time.

SUMMER AND WINTER HAIL.

Hail shows rain in another transformation, when it has been converted into ice. Hail is confined mostly to the temperate zones of the earth, and may occur in either winter or summer. Winter and summer hail usually vary markedly in size, structure, and aspect, and presumably they differ much in origin. Winter hail is usually formed as a result of melted snow falling through a cold stratum of air on its way to the earth, and becoming congealed therein. It is peculiarly a product of the southeastern quadrants of general storms, and often occurs over wide areas. Winter hailstones are usually transparent, and of small size, one-thirtieth to one-eighth inch in diameter, globular or pear-shaped in form, and containing minute air-tubes and bubbles.

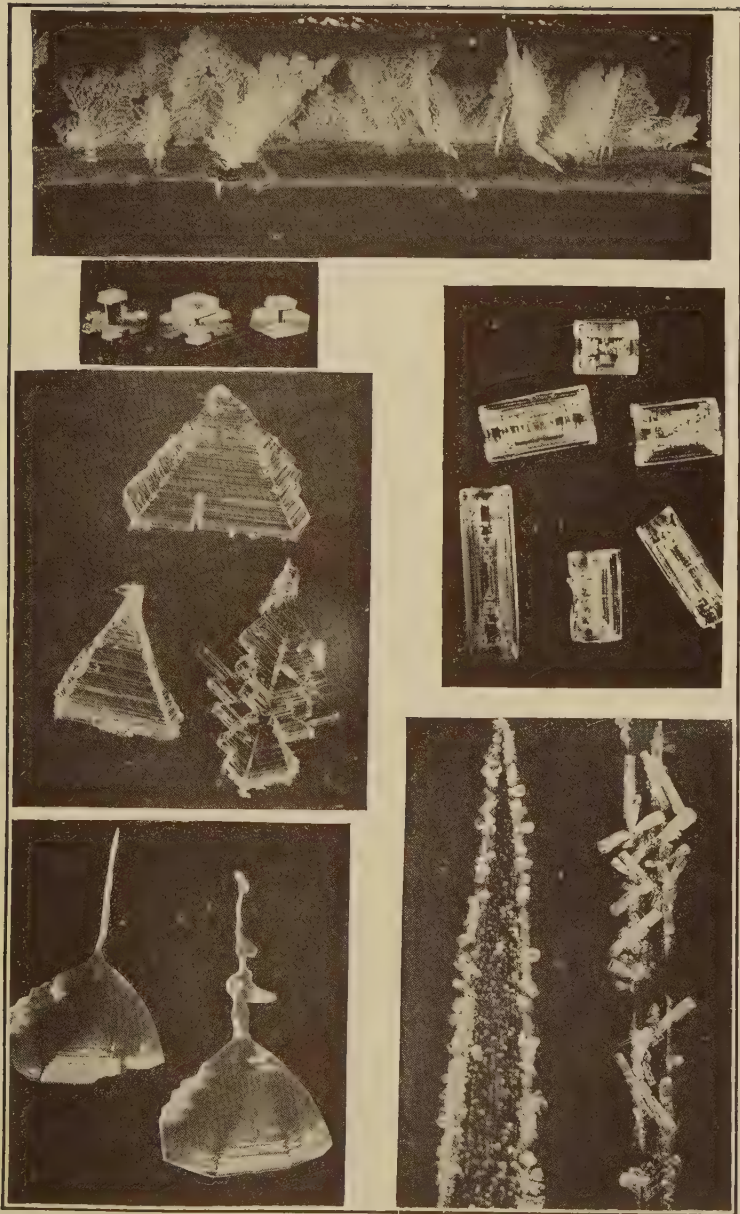
A hail storm in summer is frequently a most awe-inspiring

phenomenon. Who has not been astonished at the descent of these large masses of ice from the summer skies, and wondered how they were formed and tossed from the thunder clouds? Various theories, none of them perhaps completely satisfactory, have been advanced to explain their formation. It may, perhaps, be nearest the truth, to ascribe it to whirlwinds in the clouds, or to powerful up-draft currents, which draw the rain and hailstones, perhaps repeatedly, far upward, after a partial descent, thus alternately subjecting them to heat and cold, and alternately coating them with rain and melted snow, and at last with solid ice.

Summer hail is commonly produced within summer thunder-showers, or within those terrible whirling storms called tornadoes, and is a purely local phenomenon. Summer hailstones may vary greatly in size, aspect, and structure in different storms, or even in the same storm. Sometimes they may be as small as are the larger winter hailstones, or be in part of large size, say an inch or more in diameter. They are usually globular, ovate or disk-like in shape, though sometimes irregular, especially when several are frozen together. They usually have an irregular center of whitish ice, and one, or several, outer layers of alternately clear and opaque ice. Each layer of the latter is thickly threaded with tubes and bubbles of air, and it is this that gives these layers their whitish aspect.

THE ARTISTRY OF THE FROST

Frost crystals exist in almost endless variety, and of many distinct types. There are those that form on calm clear nights in the open, and those that form upon the window panes, and in various other confined and enclosed situations. The former are called hoar frosts, of which there are several types and varieties. Some grow on thin tabular planes, and others on columnar or cylindrical planes, or into cup-like forms. The crystals of the mischievous "early frosts" in the fall are commonly of the columnar type, and collect in a most beautiful manner upon plants and other objects, as our photograph of a grass-blade covered with this kind of frost makes plain to us.



FROST CRYSTALS, TABULAR AND COLUMNAR FORMS.

The tabular forms of frost are more common to the cold, calm, clear nights of winter, and to low temperatures. These possess much variety and beauty of form and structure. Some are frail, branching and tree-like, others more solid and leaf-like. The latter frequently possess a prettily veined or lined structure, due to their growing outward, layer by layer. When such collect in clustered array on boards or fences they look not unlike tiny flocks of butterflies, turned to ice, or like leaves wrought in crystal.

The frosts build their fairy structures in all sorts of out-of-the-way places, and adorn almost every object under the winter sky. Crystal pendants are hung upon the shrubs and grasses overhanging pools, springs, and icy terraces; elegant clusters collect upon the brook and pond ice, in zero weather, often associated with long slender needles. But when, as occasionally happens, frost collects so abundantly that all nature is clothed with it, and every tree, bush and plant is coated with a glittering white plush, all the familiar landscape is beautifully transformed into a scene from fairyland.

One of the interesting facts about hoar frost is that the several types of structure, rarely or never appear together, or in anywise equal measure, on a given night. Always some one type greatly predominates; and if the other, or opposite type appears at all, it will usually be upon the soil or upon some object lying upon the ground. Another notable feature is that the frost crystals collect and arrange themselves upon different objects in a different way. Sometimes the edges of objects, as plant leaves, will receive the most crystals: again, their faces and upper surfaces may collect the most frost. Singularly enough, the tips of the grass blades, which collect the dew so copiously, fail to collect hoar frost in greater quantity than elsewhere on the leaf. Sometimes when a very gentle current of air flows steadily from one direction, crystals of tabular frost will collect almost wholly on one side only of a twig or other object, as in the example photographed.

The most beautiful and artistic, as well as varied and seemingly imitative creations of the frost, appear in the winter upon our window panes. It is indeed fortunate that Jack Frost's masterpieces are wrought in plain view, where they may so easily

be studied and enjoyed. Very correctly, from the scientific point of view, as well as charmingly in description, has Hannah Flagg Gould depicted his mischievous adventures:

The Frost looked forth, one still, clear night,
And he said, "Now I shall be out of sight;
So through the valley and over the height
In silence I'll take my way.
I will not go like that blustering train,
The wind and the snow, the hail and the rain,
Who make so much bustle and noise in vain,
But I'll be as busy as they!"

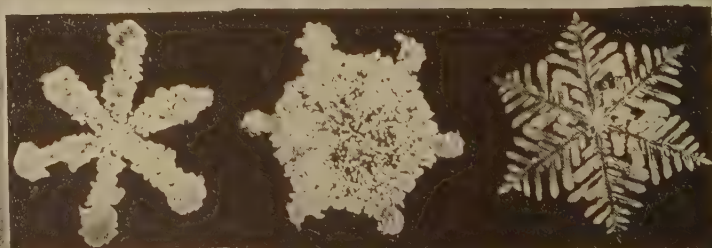
Then he went to the mountain, and powdered its crest,
He climbed up the trees, and their boughs he dressed
With diamonds and pearls, and over the breast
Of the quivering lake he spread
A coat of mail, that it need not fear
The downward point of many a spear
That he hung on its margin, far and near,
Where a rock could rear its head.

He went to the windows of those who slept,
And over each pane like a fairy crept:
Wherever he breathed, wherever he stepped,
By the light of the moon were seen
Most beautiful things. There were flowers and trees,
There were beves of birds and swarms of bees,
There were cities, thrones, temples, and towers, and these
All pictured in silver sheen!

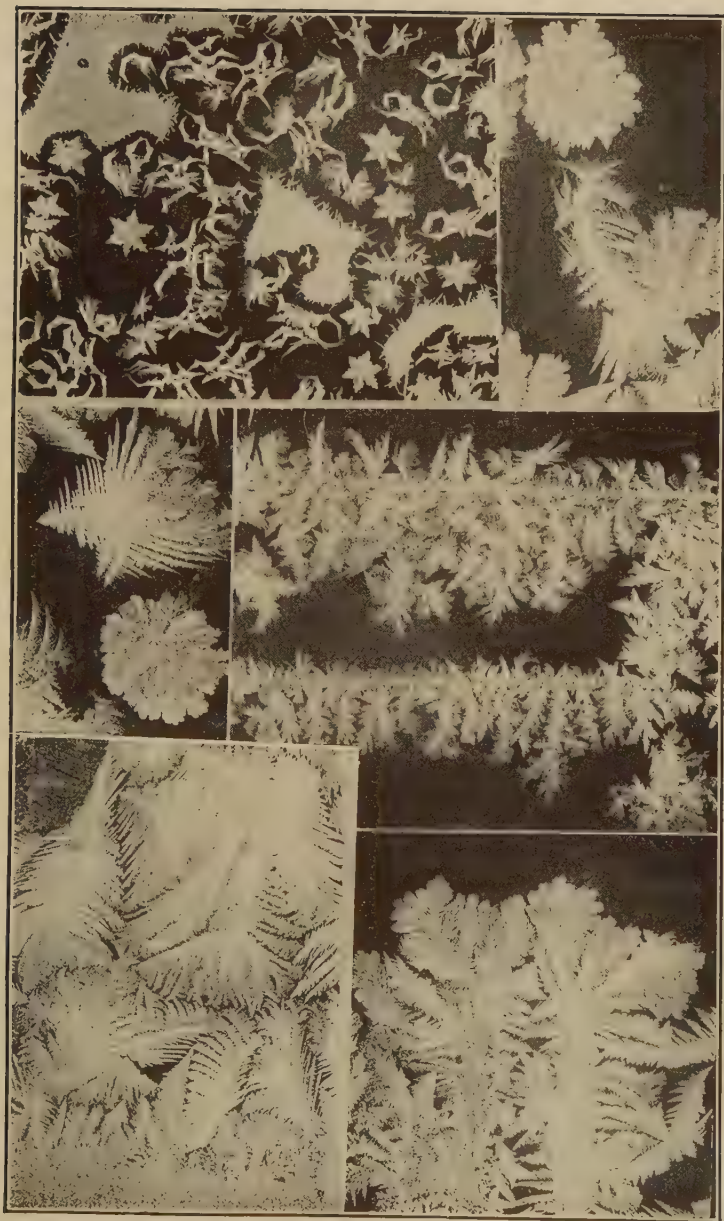
But he did one thing which was hardly fair,—
He peeped in the cupboard, and finding there
That all had forgotten for him to prepare,—
"Now, just to set them a thinking,
"I'll bite this basket of fruit," said he;
"This costly pitcher I'll burst in three,
"And the glass of water they've left for me
"Shall 'tchick' to tell them I'm drinking."

Window frost forms only upon dry glass. It may be distinguished from the larger and more showy and feather-like crystallizations of ice, which also form upon panes, but only on the outside of those that are wet, by the freezing of the film of water and which is more properly termed window ice. Window frost, on the contrary, is the result of the crystallizing upon the inside of cold window panes of the moisture of the air indoors.

True crystals of window frost sometimes form in very cold



GRANULAR SNOW. WINDOW ICE. DEVELOPMENT
OF SNOW CRYSTALS FROM LOW CLOUDS.



FROST WORK ON WINDOW PANES.

weather, even within warm living rooms. This is possible because the intense outer cold chills the glass, and also the film of air immediately next to it on the inside. In this frigid space the water molecules within the indoor air collect, condense and form themselves into the exquisitely beautiful and varied structure of the frost.

Fourteen or more types or varieties of window frost may be distinguished, only two of which, the serrated-linear type, and the tree-like or (arborescent) type, arise upon the windows of heated rooms. All the others are to be seen only on very cold glass. The individual crystals of each type also exhibit a great diversity among themselves, hardly two being just alike, and some appearing only under certain conditions of temperature and humidity, the more solid ones forming only during zero weather. The most common type, the linear, consists of long, slender serrated lines, which form within minute striations or scratches upon the glass. It often happens that a name scratched upon the glass by some idler with a diamond in his ring will be exquisitely reproduced in frost while the remainder of the pane remains clear.

We can see running all through the magic designs of the window frost the effort of the water molecules in the air to build themselves as nearly as they can into crystal structures in harmony with the rule of six. Were the glass of even thickness, equally coated, and free from specks of dust, scratches, and microscopic roughness and projections, the crystals, when truly crystalline, would appear in regular six-cornered, or six-petaled stars, greatly resembling snow; but the inequalities mentioned prevent free and symmetrical growth, and hence we more often see mere parts of crystals, than whole and perfect ones. Furthermore, certain varieties of window frost crystals are formed in part of particles of water larger than molecules, and all such develop along fanciful and erratic lines.

It adds much to our pleasure in these charming and elegant window-pictures that we can actually watch their growth almost from start to finish; and one can but wonder why a massive design is wrought at one point on the glass, while near by arises something resembling coral, or a balsam fir, or a six-pointed star.

THE BEAUTIFUL SNOW

Snow is the crystallized moisture of the air. It forms freely, in all climates, but in the tropics it rarely reaches the earth unmelted, except on the tops of lofty mountains. Like rain it is only in part a product of the clouds, only granular snow being due to cloud condensation. True snow crystals form from the molecules of water in solution within the air, at various heights above the earth, and usually within the clouds; but snow is produced in quantity only when that most impressive phenomenon called a storm is in progress, when the skies are leaden and winds are rushing forward. There, amid the surging clouds, their only support the uprushing winds, the snow crystals are born, and the strange and mysterious forces of the earth and air, hovering over and about them, help mold them into those forms of exquisite beauty that fall to our view.

The wonders and beauties of the snow are almost beyond finite understanding. It is beautiful in the moss, whether sculptured by the wind, loading the bending boughs of evergreen trees, floating in feathery cirrus cloud, or crowning the mountain tops with diadems of dazzling whiteness; and it is marvelously beautiful in detail when its star-shaped crystals are seen separately. How minute and evanescent is each by itself, yet how mighty they become when millions are massed together, as in the polar ice-caps, or in the mantles of snow covering thousands of square miles of the earth in winter. Those mighty ice rivers called glaciers, that, in many regions, form and flow down from lofty mountain chains or peaks, eroding and wearing away the rocks as they flow irresistibly on, are composed of snow crystals, massed and merged together by stress and pressure into ice. So also are the broad sheets of ice, thousands of feet in thickness, forming the ice-caps of Greenland and of the Antarctic continent.

The winds play an important, though indirect, part in their formation of snow crystals, for they waft the water-molecules within the air, from far and near, toward the storm centers, and then upward to the clouds, and mix them there with the cold currents of the upper air. This chills them to the point where



FROST PAINTING, AND SNOW CRYSTALS.

they can come under the action of crystalline law, and unite and crystallize into snow-flakes.

All snow, however, is not crystalline,—that is, formed of true crystals. A considerable part, the granular snow-pellets, and the white and thick granular snow-stars so often seen in winter, consist of cloud-particles (liquid droplets) assembled and frozen together. Cloud-particles are not single and separate molecules of water; but groups, aggregations of water molecules, and of vastly greater dimensions than any single molecule. Their unrivalled beauty is doubtless due to the fact that the molecules of water in the air, forming in so thin a solvent, are permitted a greater freedom while arranging themselves in crystal form than is permitted the molecules of other substances, when crystallizing in denser solvents, such as liquid sand minerals. The snow, moreover, crystallizes while being subjected to varied conditions, temperature, pressure, etc., and this helps to give complexity and variety to their forms.

Snow crystals assume almost infinitely varied shapes, yet nearly all are variations of the hexagonal plan. This is perhaps the most marvelous thing about them. Thousands, no two alike, have already been photographed and drawn, yet without exhausting the number of new designs. All that the storms shower down upon the earth, however, are neither perfect nor beautiful—indeed the majority are not; yet almost always some part, at least, of any snowfall contains countless novel and surprisingly constructed crystals.

Singularly enough, the more perfect forms are not usually evenly distributed among the snows of all parts of a given storm, but ordinarily within the western quadrant only.

Snow crystals do not usually spring into form all at once. They begin as tiny stars or disks—the latter may be frozen cloud-particles—and grow while falling down through the clouds, whenever they and the air around them are momentarily quiescent. They receive a layer or other addition at one place, an adornment at another, as they slowly descend earthward, or as the winds may waft them about. The temperature wherein they form, and the rate at which they grow, largely determine their shape and aspect. Those that grow rapidly, in relatively mild

and humid air, as within the lower clouds, usually assume large and open branching forms, while those that grow slowly, and in a very cold air, as in the intermediate and upper clouds, are smaller and more solid.

The crystals of snow may at one time assume frail, branching, tabular forms, very showy and elegantly beautiful in outline, at others be more solid and mosaic-like, with exquisite interiors. Kite-shaped ones are occasionally met with. Often branching accretions are received at lower cloud-levels, around the more solid, mosaic-like nucleus, thus combining the peculiar beauties of both types in one, and erecting an ideal type, unapproachably lovely; or, mosaic-like tabular crystals form at the ends of tiny columnar crystals, making a cuff-button-shaped combination termed a doublet. Crystals falling during zero weather, and larger ones produced during general storms, frequently consist in part of tiny six-sided columns of ice. Many of these are more or less hollow, and are pointed at one end, while others are blunt at both ends. Frequently a snowfall will consist of needle-like forms, or of granular stars or pellets, both products of the lower clouds.

The individual crystals, when tabular, are almost infinitely varied even among themselves; hardly two of the branching ones are ever exactly alike, nor are the more solid kinds more uniform. The explanation is that the crystallizing agencies and conditions are rarely the same for an instant.

The structure of most snow crystals, especially of the tabular kind, is usually wonderfully complex and beautiful. They are often thickly threaded with air-tubes and bubbles, and with softly modulated lines and shadings, arranged with elegant symmetry, as may be seen by consulting the photographs herewith. These air-tubes and shadings are doubtless caused by the joining of branch to branch, layer to layer, or segment to segment, as the crystals grow. Tiny spaces of air are thus bridged over and imprisoned within them, as the older portions are from time to time made more solid, as growth progresses. All internal features of this character—all the dots and bars and fairy-like hieroglyphics—within them, possess a most fascinating interest, because they show more or less perfectly the varied



SNOW CRYSTALS



SNOW CRYSTALS.

shapes that the crystals assumed as growth proceeded. The snow is, indeed, most wonderful, whether considered in relation to its place of origin and manner of formation; or to its habits of growth, abundance, and power of transforming and beautifying nature's aspect; or to its practical service in the world. Where plentiful, as in the polar and temperate zones, it blankets the earth from the severe cold of winter, and helps to conserve its heat, and thus to preserve its vegetable life. It shares with the rain in the beneficent work of supplying the land with moisture and refilling the rivers, lakes and oceans, with water to replace that sucked up by the thirsty air. In one respect it is better in this service than the rain, for its massive deposits do not race away in floods, sometimes destructive, and then leave the river beds empty for long periods, but by slow melting sustain the streams during the dry months of the year, and feed innumerable refreshing springs that burst out at distant points.

"All day had the snow come down,—all day
 As it never came down before;
 And over the hills, at sunset, lay
 Some two or three feet, or more;
 The fence was lost, and the wall of stone;
 The windows blocked and the well-curbs gone;
 The haystack had grown to a mountain lift,
 And the wood-pile looked like a monster drift,
 As it lay by the farmer's door.

"The night sets in on a world of snow,
 While the air grows sharp and chill,
 And the warning roar of a fearful blow
 Is heard on the distant hill;
 And the norther, see! on the mountain peak
 In his breath how the old trees writhe and shriek!
 He shouts on the plain, ho-ho! ho-ho!
 He drives from his nostrils the blinding snow,
 And growls with a savage will."

THE STRUCTURE OF ICE

In winter, when the air is cold, every piece of exposed water is the scene of an intense, although invisible activity. The molecules of its surface, chilled into relative quiet, draw together in countless numbers, become re-arranged, and form themselves under crystallizing influences into the structure we call ice,—

that is, water become solid. All ice (except that of glaciers, and such as is accretionary, as in icicles) although apparently formless and transparent, is composed of a multitude of minute crystals so perfectly merged together, and so translucent, as to be invisible except when viewed in just the right way. We may understand this, and even see the process of growth, by placing a bowl of water in the still air of a sufficiently cold room and watching the formation of its icy covering. Put the experimental dish in a strong light, and lay on its bottom, beneath the water, a mirror or piece of looking-glass, for the reflected light will aid us in detecting the birth and growth of the delicate objects we wish to examine.

The crystallizing force will first manifest itself around the edges of the dish, as freezing first occurs along the banks of a pond, and thence progress inward toward the center of the water-space. Needle-shaped spicules of ice first appear on the surface at the rim of the bowl, and multiply steadily, all pointed inward, and springing suddenly into view as if shot out of the increasing film that borders the miniature pond under our eyes. As these needles multiply the older ones throw out branches, and merge into neighboring spicules, until finally the whole surface is changed into a solid film.

This is the method by which ice grows on water which is perfectly still, but out of doors, in a river or pond, it is usually disturbed, either by wave action under the wind, or by the flowing of a current. Such movements break up the forming ice-film, the effect of which is to cause nature to accomplish her object by another method, as we may see experimentally in our dish in the window. Let us break to pieces the film which is just now complete over its surface. A surprising thing follows. Myriads of tiny round disks, hexagons and six-petaled star-like ice-crystals, come into view on the surface of the water. Sometimes the variety of nuclear forms will be even larger, owing to the formation of queer, long-pointed crystals, and other odd shapes.

These tiny ice crystals, of whatever shape or form, possess smooth edges at first, and are hardly thicker than the thinnest paper. Watch them grow, and note how readily they merge



TABULAR SNOW CRYSTALS.

and freeze together, and form tiny patches of ice film; but only those that lie apart by themselves, grow in a symmetrical manner. Those crowded together grow unevenly, and mainly upon those parts lying next to unoccupied crystal-free spaces of water. Every type of ice crystal, and there are many, shows wonderful phases of growth, and richly repays study and observation. Once formed, they pass successively through the smooth-edged, scalloped, rayed and branching stages of growth before merging to form solid ice.

The histories of the discoidal and of the star-shaped crystals, are perhaps of most interest. The aspects of the several growth-stages of the former are well shown in our group photographs. Choose one or more of the round discoidal ones and watch their changes of form if possible, by the aid of a reading glass or pocket lens. Tiny scallops soon form completely around their edges. Watch closely, and it will soon be noticed that certain of these scallops, situated at six equidistant points around their edges, are growing faster and becoming larger than their fellows. Crystal habits of growth are now changing, from the round habit to the hexagonal one. That mysterious something called crystallic force, is asserting itself within these tiny round disks. It endows these six equidistant points with excessive attractive powers for the water-molecules. Hence these parts draw most of the neighboring molecules to themselves, and grow henceforth much the faster. The favored scallops soon push outward and assume the ray stage, and the crystals become beautiful six-pointed stars, or ice flowers.

Now watch the main rays closely. Soon it will be noticed that these in turn are becoming scalloped around their edges. These scallops soon grow outward into branches, and convert the crystals into branching six-pointed stars. This is their completed or mature stage, and henceforth they merely grow larger and become more complex, until at last they meet and merge with other crystals, and freeze together to form a solid ice film.

The life-history of those crystals which have a beginning in either the hexagonal or in the star form, is similar. Select one or two of these, and keep them apart from the others, by poking aside

intruders with a fine splint or a piece of wire, and note how they, too, grow into branching six-pointed stars. Not all, however, increase in this beautifully regular and symmetrical way, and the manner of growth of some of the odd nuclear forms is most unusual and past understanding. Occasionally, scallops will form only at one side of an irregular germ-crystal, and grow outward in the form of long and sinuous branches, thus producing the coral type of ice crystal. In other cases, one-sided growth of this kind may produce the horse-shoe type, or something else equally queer. One can only speculate as to the nature of the subtle forces or conditions that make crystals of a given type, growing side by side, assume forms so unlike one another.

The formation and growth of countless myriads of similar ice-crystals goes on wherever ice forms; and they merge and freeze so solidly together that often not the slightest trace remains in the mass.

The sunlight, however, has a way of bringing them into view by causing a slight internal melting without softening the surface of the ice; which explains how skaters sometimes catch glimpses, deep in the body of the ice over which they are gliding, of stars and flower-like forms which arouse their wondering curiosity; but this can only happen on a sunny day.

When during intense cold the water of a shallow pond or river becomes chilled through, ice crystals sometimes form not only at the surface but within the depths of the water, filling it with what is called "mush." Owing to the fortunate fact that ice is lighter than water, due, of course, to the air locked up in tiny chambers enclosed by the merging crystals, the little separated masses of "mush" rise and attach themselves to the under side of the sheet which covers the surface, or, in its absence, float down the current till something stops them and allows them to freeze together into an irregular mass.

Sometimes, however, if the cold is accompanied by clear skies, allowing the bottom of a river or pond to radiate freely its heat, the rocks and gravel there presently become so chilled that the crystals of mush-ice floating in the water collect upon these objects and remain on the bottom, forming what is called



ICE CRYSTALS AND THEIR DEVELOPMENT.

anchor-ice. This often accumulates so greatly upon the bottoms of northern rivers, notably the St. Lawrence, as sometimes to dam them and cause floods; or it may do damage by collecting thickly in the flumes and on the wheels of mills, in canal locks and in similar places.

The field of investigation open to the student of ice phenomena is indeed broad, aside from its common manifestation on frozen rivers. The banded ice-columns that early in the winter arise like magic above peaty ground are interesting: so also is the ice that coats wet window panes,—often exquisitely elegant in its crystallization, resembling tufts of splendid plumes radiant in the sunlight.

We have yet to learn, however, why there is so great a diversity of form among crystals growing side by side on the water, and under seemingly identical conditions, temperatures, etc. They should, according to our crystallographic philosophy, be all alike in form. The experimental side of ice-crystal formation, and indeed of frost formation also, is as yet hardly touched. It still remains to be seen what effect, if any, certain salts dissolved in water in process of freezing will have on the habits of growth of the crystals. The varied forms of water, the dew, rain, snow, frost, ice, clouds, etc., are all rich in opportunities for new discoveries in science; and it may be expected that students and crystallographers will yet learn much regarding the factors and conditions that govern and modify their forms and habits of growth.

EVOLUTION AND NATURE STUDIES

Ocean Depths and Ocean Rivers

By AGNES GIBERNE

PEOPLE are slow to realize how modern is our knowledge of ocean-depths. About three hundred years ago a famous navigator made the first sounding which went below two hundred fathoms—that is, about one hundred feet deeper than the height of Beachy Head from the shore. He at once decided that, by a happy chance, he had alighted upon the uttermost depth in the ocean.

To him it was an awe-inspiring profundity. Yet, when viewed beside such abysses as have been recently discovered, depths of five and six miles, his little “deep” was as a saucer beside a lake.

It is not easy to picture to ourselves the changeless calm of those abysses—those five or six miles of underwater, with nothing from sea-level to sea-floor to break the dead monotony.

Throughout such regions storms, no matter how terrible, have no power. Winds cannot reach them. When Ocean’s surface is lashed by a hurricane into wild commotion, that commotion is superficial. It means a furious stirring and flurry of upper layers; and it means no more.

If, at the height of some fierce tornado, a sailor could leave his tossing, straining ship, and could dive far into the sea, keeping breath and sense and life, he would soon quit the turmoil, and would find himself in a scene of deep repose. As everyone knows, the idea of submarine ships actually doing this is being mooted, as one of the new projects of the twentieth century.

Wave-motion does not descend much below the surface. It

is believed that the depth of water affected by a wave is usually about equal to the space which divides crest from crest. So, if we are looking at little ripples, flowing one after another, with crests perhaps one foot apart, we may suppose that the water is disturbed by those ripples to a depth of about one foot. Or, if we are watching larger waves, with crests twenty feet apart, we may suppose the disturbance to reach down to a depth of some twenty feet. And if our gaze is fixed on dignified Atlantic rollers, with crests six or eight hundred feet apart, we may suppose that the sea is affected to a depth of six or eight hundred feet—less and less affected the deeper we go down.

Six or eight hundred feet, compared with six miles, are hardly more than a man's skin compared with his body. And beyond the shallow depths where wind and wave have sway, we come to a region of profound calm.

This repose does not mean stagnation. Ocean's waters are ever on the move, traveling this way and that way. Currents exist far below, as well as at the surface; but they are generally slow and placid, not rough and hurrying. Old Ocean's excitability lies all outside. Superficially he is soon upset; but deep down he is composed.

A great deal of discussion has taken place as to possibilities of light in those depths. Are they black with midnight darkness? or do faint glimmers of daylight creep through?

Ocean-water, like other water, is transparent. Any substance is transparent, when thin enough,—even gold. A very thin film of water is not, however, needed for transparency. Many feet, even many yards, may be seen through, if clear and pure. Few of us have not, at one time or another, looked down from a boat, to see golden sand, variegated pebbles, or small fishes swimming about at a considerable depth.

Thus with water, as with denser materials, transparency is merely a question of thickness. As the thickness increases, more and more rays of sunlight are taken captive, and the water becomes less and less translucent, till at length, if we could get deep enough, we should find ourselves to be surrounded with blackness.

Another feature of ocean-depths is that of immense pressure.

We bear a certain degree of it in that other and lighter ocean—the atmosphere. A man of medium size has upon his body about thirty thousand pounds' weight, or some fifteen pounds to the square inch. But this is nothing to what he would have to endure down in ocean-waters. At a depth of one mile, an extra ton would be piled upon each square inch of his body; two miles down, would mean two extra tons on each square inch; three miles down, three extra tons; and so on. The load would soon become intolerable.

For many years scientists maintained that in such depths no life could exist, since no bodies could withstand the awful pressure. Yet we now know that frail jellyfish, fragile shell-inhabitants, do withstand it, flourishing there by myriads.

Perhaps the fact was somewhat overlooked, that the pressure upon a living creature is not only inwards from without, but also is outwards from within. This is true of ourselves in the ocean of air, breathing air. It is true of creatures in the ocean of water, breathing water.

Much less than the weight of thirty thousand pounds might crush a man flat, were it not for the resisting pressure from within. If for one instant he could empty his body of all inner air and liquids, and could so harden his skin that no air should squeeze through its pores, he would be pressed as flat as a pancake by the surrounding atmosphere.

A story has been told, illustrative of this. Once upon a time a clever fellow started an original idea. He proposed to make a balloon, which should mount skywards, not from being full of hydrogen gas, but from being emptied of air. Being then lighter than the atmosphere, it would, he said, of course rise.

So far as the reasoning went, it was faultless. It only did not go far enough.

The balloon being made, he named a day for its ascent, and asked many friends to witness his triumph. At the last moment, all air was withdrawn; and everybody waited in expectation, hoping to see the novel balloon skim lightly above their heads.

But the inventor, while using strong materials, had failed

to make full allowance for the tremendous pressure of the air, when counteractive pressure from within should have been done away with. As the air was drawn out, the sides of the balloon collapsed, being crushed together as an empty egg-shell may be smashed in a boy's hand. Instead of soaring gaily upward, the would-be aeronaut stood on earth, scanning with disappointed eyes a flattened and useless shell.

A diver going down into the sea has a much increased weight upon his body; but he does not suffer from it to a serious extent, provided that he is not raised or lowered too fast. Much depends upon this. Both men and beasts can endure a good deal of alteration in the degree of pressure, whether from air or from water; but they cannot bear very abrupt changes. Hearts and lungs need time for growing accustomed to a fresh condition. In early days of diving this was not understood, and some divers lost their lives through being too hurriedly hauled up.

The same has been noticed in animals brought quickly from great depths. They have been constantly found in the net or trawl, dying or dead, their bodies swollen and even bursting from the lessening of pressure. It was natural that at first the belief should arise of life being in those parts impossible. Now we know that animals die in the act of being drawn up, and that they live and flourish in profound depths, unaffected by the vast load of water.

The weight that a man can endure is not to be compared with what fragile sea-creatures thrive under. Beyond a depth of some two hundred feet or more, the pressure becomes too great for any human beings; yet animals are found at depths of three or four miles. But the fact that man breathes air, and that animals in the sea breathe, in a sense, water, makes an enormous difference in their power to resist pressure.

One might suppose that the terrific weight of miles of water would squeeze lower layers to a smaller bulk. Water is, however, very difficult to compress; unlike air.

At the bottom of the sea, four or five miles deep, the weight is said to be equal to about four tons upon the square inch. If this tremendous load were pressing upon a mass of air, eleven thousand cubic feet in quantity, the whole would be crushed

together into only twenty-two cubic feet. But the same weight pressing upon the same quantity of sea-water, would merely reduce its size to ten thousand cubic feet. So there is not much difference between the density of sea-water near the surface and sea-water at a great depth.

Not only are ocean's depths calm and free from storms; not only are they black with midnight darkness; not only are they heavy with the weight of miles of water overhead; but also for the most part they are cold.

Changes from season to season, like changes of weather, are superficial. At a depth of about six hundred feet, seasons have ceased to be. There, summer and winter, autumn and spring, exist no longer. The dead level of calm and darkness is also a dead level of uniform weather and unalterable climate. Where changes of cold and heat do come about, they are very uncertain, and usually they are due to other causes than those which bring about the succession of seasons upon earth.

Many remarkable facts have lately come to light with respect to ocean temperatures. In far northern and far southern regions, near the two poles, the whole sea is very cold. One might expect the converse of this in tropical regions—a whole sea intensely warm. But this we do not find. The shallower parts—those included in the hundred-fathom limit—may be nearly as warm below as above. When, however, deep-sea soundings are made, when the registering thermometer is despatched on its mission of inquiry miles below the surface, then the report brought up is generally of great cold.

In almost all deeper parts, the tale is told of a frigid under-layer,—of water nearly and sometimes quite down to the freezing-point of fresh water. This, not only in Polar seas, not only in temperate oceans, but in the hottest portions of the tropics. The Atlantic, near the equator, is icy in its depths.

A reckoning has been made that, if the floor of the whole ocean, omitting shallower parts, could be divided into one hundred equal portions, ninety-two of those portions would be found covered by water at a temperature of less than 40° ; and only eight of them would lie under warm water. The vast mass of the ocean is cold, with a thin warm layer over certain districts.

Little doubt can there be that this under-layer is largely fed from polar regions.

We know that cold ocean-rivers pour from north-polar regions to the south, both in the Atlantic and in the Pacific. A general creeping under-flow of icy waters towards the equator evidently balances the general surface drift of warm waters towards the poles. Since cold water is heavier than warm, it would naturally find its way to lower depths, leaving the warm light liquid to float on top.

In the Mediterranean Sea a marked contrast is found. There no ice-cold layer is spread over the bottom; and the water in its uttermost depths—over two miles and a quarter—does not sink below the temperature of 54°F. The heat of the sun in Southern Europe can hardly be compared with the heat of the sun over the Indian Ocean. Yet the latter has water far below the surface down to at least 35°.

Practically the Mediterranean, despite its depth, may be looked upon as an inland sea. The one opening which connects it with the open ocean is not only comparatively narrow, but also is shallow, being less than two hundred fathoms deep. The water on this dividing ridge remains at about 55°, and the Mediterranean throughout, to its greatest depths, keeps to about that same degree of warmth. No entrance is afforded to the heavy cold currents from polar regions.

The Red Sea is separated from the Indian Ocean by a similar ridge, and the same result is seen there. Over the floor of the Indian Ocean lies a carpet of chill water. But the whole body of the Red Sea never sinks, in summer or winter, below 70°F. Here, too, the cold streams are not able to surmount the barrier.

In many deep mid-ocean hollows, cut off by surrounding sub-ocean walls of rock, the same is found again—warm water within the hollow, cold water on the ocean-bed outside.

RIVERS IN THE SEA

Actual rivers in the ocean; distinct streams of water, flowing over a bed of water, with banks of water. Not merely

one or two such rivers, but scores of them, hundreds of them, great and small, in all parts of the world.

Chief perhaps in importance is the Gulf Stream, that vast flood which pours out of the Gulf of Mexico, and acts as a winter heating apparatus for the west of Europe. Though by no means the largest of ocean streams, it is one of the most useful to man.

After quitting the Gulf, it swiftly flows through the Straits of Florida; then spreads out into a river, about fifty miles wide and over two thousand feet deep, journeying at a rate of some sixty miles in twelve hours.

For a while it hugs the American coast; but, happily for Europe, it forsakes this friend of its youth, and wanders to the northeastward across the Atlantic.

To call it a "river" is no mere figure of speech. Near Halifax the separation between warm and cold water is so sharp, that those on board a ship may know what latitude they have reached, on entering or leaving the stream, by simply dipping a bucket in the water and taking the temperature. Literally the Gulf Stream is a warm river, flowing over a bed of cold water, with cold-water banks.

As far as Cape Hatteras the stream clings to its early friend; and after that the American coast knows it no more, being left to the mercies of a very different acquaintance. An icy stream flows southward from the far north, clinging to the coast of North America, while those in western Europe benefit by the presence of the warm current which travels over to them. This stream has been described as forming a "cold wall" to the mild Gulf Stream.

Fan-like, the Gulf Stream spreads as it journeys, growing gradually wider and wider, shallower and shallower, cooler and cooler—yet the last so slowly that, even off the coast of Scotland, water nine hundred fathoms deep is found to be at 40°F.

How strongly this mass of warm water affects the air above it is well known to sailors. When passing from the stream to the outside ocean, or from the ocean to the stream, they often change in a few hours from a warm to a cool or from a cool to a warm climate. The atmosphere is ever ready to tune its mood sympathetically to that of the ocean over which it sweeps.

But for the immense stores of heat carried northward, and given over to it, the English climate would be different indeed from what it now is. That is why their fellow-subjects in eastern and central Canada, living no farther from the equator than do the English, suffer from an intensity of cold in winter which they never endure. It is difficult to realize that parts of ice-bound Labrador and of Canada, where the thermometer often drops to 40° below zero, are no farther north than London and Paris; while Newfoundland lies actually more to the south than Erin's green Isle.

Turning to the Pacific Ocean, we find there a corresponding river, again flowing to the northeast. Just as the Gulf Stream wanders across the Atlantic, so this river wanders over the Pacific, carrying stores of tropical warmth to opposite coasts. At its quickest, it is less rapid than the Gulf Stream, and about three times as wide. It too, as it journeys, becomes gradually broader, shallower, slower, colder.

This "Kuro Sivo" or "Black Stream," so named from its dark color, flows outside Japan, and then strikes freely for the northern coasts of North America. And because of its work as a winter heating apparatus in Alaska, the humming-bird is found at a latitude which, on the other side of the American Continent, means, not the play and whirr of humming-birds in a soft air, but the disporting of walruses among ice floes.

As in the Atlantic, so in the Pacific, the warm northward-traveling current is balanced by a cold southward-traveling current. The Arctic stream of the Pacific is not so marked as that of the Atlantic, perhaps partly because of the much shallower outlet from the Arctic Ocean; still it is quite chilly enough in its effects upon the Siberian climate. Here again the cold stream acts as a "wall" to the warm river flowing the other way.

More reasons than one may help to explain why these two currents slant off to the eastward instead of pouring due north. The shape of the various coastlines has something to do with it; also the presence of ridges and hollows in the ocean-beds, and the resistance of other contending currents. A river, either on land or in the sea, will always travel where it finds least opposition.

One main cause, however, is the whirl of our earth upon its axis. This, which greatly affects the directions of prevailing winds, alters also the lines followed by ocean rivers.

A current starting from near the equator for the north shares in the rapid rush of the earth's surface, which at the equator spins eastward at a rate of about one thousand miles each hour. As the volume of water gets farther north, it reaches parts of the earth which are whirling more slowly, while it has not lost much of its own eastward whirl. A sideways flow is the result, changing the northward into a northeastward direction.

But a stream starting from the far north for the south is affected in the opposite way. Near the north pole the earth's surface hardly moves at all; and the southward-flowing current, being weighted with northern inertia, takes a contrary course to the current flowing north. It lags more and more *behind* the faster-revolving surface, and so wanders westward instead of eastward. Or, if prevented by the land from so doing, it hugs the coast which hinders it.

So the *pull* of the two great streams in the Atlantic is exactly opposed, each to the other. That of the Gulf Stream is towards the east; that of the Labrador Stream is towards the west; and the resolute manner in which the two refuse to mingle may be partly due to this fact.

If our earth could be made to change the present whirl from west to east, and to revolve instead from east to west, those two great currents would alter their directions. The Gulf Stream would hug the American coasts, and the Labrador would find its way over to Europe. Then the British Isles in winter would know a temperature of 30° or 40° below zero, and the Canadians would experience soft, damp winters and moderate summers. Perhaps they would no more welcome the exchange than would the English.

Then, too, the Black Stream would cling to the Asiatic side, transforming the climate of western Siberia, and the cold Arctic river would put a speedy end to hummingbirds in Alaska. But abundance of ice floes would soon be awaiting the walruses which would have to emigrate from the other side of the continent.

A good deal of discussion has been held as to whether England owes its mild climate to the Gulf Stream alone, or whether that Gulf Stream is merely a part of a general northward movement of Atlantic waters from the tropics towards the pole. The question has been warmly contested; and no doubt on both sides, as generally is the case, truth has been mixed with error.

The Gulf Stream cannot be viewed as a separate entity. Its very birth in the Gulf of Mexico depends on a great mass of water ever flowing from the southeast into the Caribbean Sea. Since so much water pours in, the same volume must pour out, and as it does so it gains the name of the "Gulf Stream."

But after quitting the Gulf of Mexico the stream does not exist alone. It becomes a leading part of the North Atlantic circulation. The whole surface of that ocean is slowly turning round and round—"Whirling as if stirred in the direction of the hands of a watch," and the Gulf Stream occupies one side or more of the vast *maelstrom*. In the center of this revolving mass of water lies a district where the motion is slight, and at that center floats an enormous collection of drift and seaweed called the Sargasso Sea.

Suppose we pour some water in a large basin, drop into it a handful of small leaves and chips, and make the whole spin gently with one hand. We shall then see how the chips and leaves will collect at the center, and will float there, almost stationary. That is what happens, on a large scale, in the North Atlantic Ocean.

Other oceans also have this steady circular movement, not of the whole body of water, but of the surface-water, down to a greater or less depth—precisely how deep one cannot say; it lessens gradually with increasing depth. The same is found also in the South Atlantic, in the North and South Pacific, and doubtless in the Indian Ocean.

To find its direction in any part, one need only lay a watch, face upwards, upon a map of the North Atlantic or the North Pacific. In both cases the water travels round *with* the watch-hands. In the South Atlantic and the South Pacific the flow is just in the opposite direction.

So both the Gulf Stream and the Black Stream are merely

parts of a big oceanic whirlpool. Each ocean on earth has its own system of circulation; and that system is part of a world-wide system. The waters are in perpetual and complicated motion. Streams pour incessantly hither and thither, to north and south, to east and west.

Two vast streams, known as the Equatorial Currents, nominally pour round the world, but really are best seen in the open Pacific, where for long distances no land meddles with their career. They flow steadily westward, one to the north and one to the south of the equator.

Between them flows a reverse stream, called the "Equatorial Counter Current." If a certain amount of water travels north, an equal quantity must travel south. Or if, as in this case, so much water runs in a westerly direction, a corresponding quantity has to run in an easterly direction. Water may be marvelously piled up here or there, by influences of land or of wind, but it cannot remain piled up, without efforts on the part of the ocean to restore the equilibrium.

Were the whole earth covered by a single unbroken sheet of water, these drift currents might circle round and round the globe for ever, undisturbed in their working. But the earth has lands as well as oceans; and when a current strikes a coast its course is altered, part at least being turned in a fresh direction.

Much discussion has taken place about the causes which bring these great Drift Currents into being.

Disturbing elements, many in number, may have had a hand in the matter. So soon as one part of the sea-surface becomes warmer than another part, movements are set going; the heavy cold water sinks, the light warm water rises, and streams are started from the one place to the other. There are also countless rivers pouring into the ocean, each helping to upset its equilibrium. Heavy downpours of rain raise the level of the sea here or there, inducing more currents.

But these are lesser causes. It is now recognized, as a fact beyond question, that the main power in starting and sustaining ocean-currents is that of wind.

EVOLUTION AND NATURE STUDIES

Some Records of Plants and Animals

By SIR ARCHIBALD GEIKIE

BROADLY considered, there are two distinct ways in which plants and animals leave their mark upon the surface of the earth. In the first place, they act directly by promoting or arresting the decay of the land, and by forming out of their own remains deposits which are sometimes thick and extensive. In the second place, their remains are transported and entombed in sedimentary accumulations of many different kinds, and furnish important evidence as to the conditions under which these accumulations were formed. These two forms of memorial deserve the most generally interesting departments of geology,—those in which the history of the earth is principally discussed.

I. *Direct Action of Living Things upon the Surface of the Globe.*—This action is often of a destructive kind, both plants and animals taking their part in promoting the general disintegration of rocks and soils. Thus, by their decay they furnish to the soil those organic acids which are recognized as so important in increasing the solvent power of water, and thereby promoting the waste of rocks. By thrusting their roots into crevices of cliffs, plants loosen and gradually wedge off pieces of rock, and by sending their roots and rootlets through the soil, they open up the subsoil to be attacked by the air and the descending moisture. The action of the common earthworm in bringing up fine soil to be exposed to the influences of wind and rain has an enormous effect. Many burrowing animals also, such as the mole and rabbit, throw up large quantities of soil and subsoil which are liable to be blown or washed away.

On the other hand, the action may be conservative, as, for instance, where, by forming a covering of turf, vegetation protects the soil underneath from being rapidly removed, or where sand-loving plants bind together the surface of dunes, and thereby arrest the progress of the sand, or where forests shield a mountainside from the effects of heavy rains and descending avalanches.

(1) *Deposits Formed of the Remains of Plants.*—But it is chiefly by the aggregation of their own remains into more or less extensive deposits that plants and animals leave their most prominent and enduring memorials. As examples of the way in which this is done by plants, reference may be made to peat-bogs, mangrove-swamps, infusorial earth, and calcareous sea-weeds.

Peat-bogs.—In temperate and arctic countries, marshy vegetation accumulates in peat-bogs over areas from an acre or two to many square miles, and to a depth of sometimes fifty feet. These deposits are largely due to the growth of bog-mosses and other aquatic plants which, dying in their lower parts, continue to grow upward on the same spot. On flat or gently-inclined moors, in hollows between hills, on valley-bottoms, and in shallow lakes, this marshy vegetation accumulates as a wet spongy fibrous mass, the lower portions of which by degrees become a more or less compact dark-brown or black pulpy substance, wherein the fibrous texture, so well seen in the upper or younger parts, in large measure disappears. In a thick bed of peat, it is not infrequently possible to detect a succession of plant remains, showing that one kind of vegetation has given place to another during the accumulation of the mass. In Europe, as my readers may already know, peat-bogs often rest directly upon fresh-water marl containing remains of lacustrine shells. In every such case, it is evident that the peat has accumulated on the site of a shallow lake which has been filled up, and converted into a morass by the growth of marsh-plants along its edges and over its floor. The lowest parts of the peat may contain remains of the reeds, sedges, and other aquatic plants which choked up the lake. Higher up, the peat consists almost entirely of the matted fibres of different

mosses, especially of the kind known as bog-moss or *Sphagnum*. The uppermost layers may be full of roots of different heaths which spread over the surface of the bog.

The rate of growth of peat has been observed in different situations in Central Europe to vary from less than a foot to about two feet in ten years; but in more northern latitudes the growth is probably slower. Many thousand square miles of Europe and North America are covered with peat-bogs, those of Ireland being computed to occupy a seventh part of the surface of the island, or upwards of 4,000 square miles.

As the aquatic plants grown from the sides toward the center of a shallow lake, they gradually cover over the surface of the water with a spongy layer of matted vegetation. Animals, and man himself, venturing on this treacherous surface sink through it, and may be drowned in the black peaty mire underneath. Long afterwards, when the morass has become firm ground, and openings are made in it for digging out the peat to be used as fuel, their bodies may be found in an excellent state of preservation. The peaty water so protects them from decay that the very skin and hair sometimes remain. In Ireland, numerous skeletons of the great Irish elk have been obtained from the bogs, though the animal itself has been extinct since before the beginning of the authentic history of the country.

Mangrove-swamps.—Along the flat shores of tropical lands, the mangrove trees grow out into the salt water, forming a belt of jungle which runs up or completely fills the creeks and bays. So dense is the vegetation that the sand and mud, washed into the sea from the land, are arrested among the roots and radicles of the trees, and thus the sea is gradually replaced by firm ground. The coast of Florida is fringed with such mangrove-swamps for a breadth of from five to twenty miles. In such regions, not only does the growth of these swamps add to the breadth of the land, but the sea is barred back, and prevented from attacking the newly-formed ground inside.

Infusorial Earth.—A third kind of vegetable deposit to be referred to here is that known by the names of infusorial earth, diatom-earth, and tripoli-powder. It consists almost

entirely of the minute frustules of microscopic plants called diatoms, which are found abundantly in lakes and likewise in some regions of the ocean. These lowly organisms are remarkable for secreting silica in their structure. As they die, their singularly durable siliceous remains fall like a fine dust on the bottom of the water, and accumulate there as a pale gray or straw-colored deposit, which, when dry, is like flour, and in its pure varieties is made almost entirely of silica (90 to 97 per cent.). Underneath the peat-bogs of Britain a layer of this material is sometimes met with. One of the most famous examples is that of Richmond, where a bed of it occurs thirty feet thick. At Bilin, in Bohemia, also, an important bed has long been known. The bottom of some parts of the Southern Ocean is covered with a diatom ooze made up mainly of siliceous diatoms, but containing also other siliceous organisms (*radiolarians*) and calcareous *foraminifera*.

Accumulations of Sea-weeds.—Yet one further illustration of plant-action in the building up of solid rock may be given. As a rule the plants of the sea form no permanent accumulations, though here and there under favorable conditions, such as in bays and estuaries, they may be thrown up and buried under sand so as eventually to be compressed into a kind of peat. Some sea-weeds, however, abstract from sea-water carbonate of lime, which they secrete to such an extent as to form a hard stony structure, as in the case of the common nullipore. When the plants die, their remains are thrown ashore and pounded up by the waves, and being durable they form a white calcareous sand. By the action of the wind, this sand is blown inland and may accumulate into dunes. But unlike ordinary sand, it is liable to be slightly dissolved by rain-water, and as the portion so dissolved is soon re-deposited by the evaporation of the moisture, the little sand-grains are cemented together, and a hard crust is formed which protects the sand underneath from being blown away. Meanwhile rain-water percolating through the mounds gradually solidifies them by cementing the particles of sand to each other, and thick masses of solid white stone are thus produced. Changes of this kind have taken place on a great scale at Bermuda, where all the dry land consists of lime-

stone formed of compacted calcareous sand, mainly the detritus of sea-weed.

(2) *Deposits Formed of the Remains of Animals*.—Animals are, on the whole, far more successful than plants in leaving enduring memorials of their life and work. They secrete hard outer shells and internal skeletons endowed with great durability, and capable of being piled up into thick and extensive deposits which may be solidified into compact and enduring stone. On land, we have an example of this kind of accumulation in the lacustrine marl which, we have found, is formed of the congregated remains of various shells. But it is in the sea that animals, secreting carbonate of lime, build up thick masses of rock, such as shell-banks, ooze, and coral reefs.

Shell-banks.—Some mollusks, such as the oyster, live in populous communities upon submarine banks. In the course of generations, thick accumulations of their shells are formed on these banks. By the action of currents also large quantities of broken shells are drifted to various parts of the sea-bottom not far from land. Such deposits of shells, *in situ*, or transported, may be more or less mixed with or buried under sand and silt, according as the currents vary in direction and force. On the other hand, they may be gradually cemented into a solid calcareous mass, as has been observed off the coast of Florida, when they form on the sea-bottom a sheet of limestone, made up of their remains.

Ooze.—From observations made during the great expedition of the "Challenger," it has been estimated that in a square mile of the tropical ocean down to a depth of 100 fathoms there are more than 16 tons of carbonate of lime in the form of living animals. A continual rain of dead calcareous organisms is falling to the bottom, where their remains accumulate as a soft chalky ooze. Wide tracks of the ocean-floor are covered with a pale-gray ooze of this nature, composed mainly of the remains of the shells of the *foraminifer Globigerina*. In the north Atlantic this deposit probably extends not less than 1,300 miles from east to west, and several hundred miles from north to south.

Here and there, especially among volcanic islands, portions of the sea-bed have been raised up into land, and masses

of modern limestone have thereby been exposed to view. Though they are full of the same kind of shells as are still living in the neighboring sea, they have been cemented into compact and even somewhat crystalline rock, which has been eaten into caverns by percolating water, like limestones of much older date. This cementation, as above remarked, is due to water permeating the stone, dissolving from its outer parts the calcareous matter of shells, corallines, and other organic remains, and re-depositing it again lower down, so as to cement the organic detritus into a compact stone.

Coral reefs offer an impressive example of how extensive masses of solid rock may be built up entirely of the aggregated remains of animals. In some of the warmer seas of the globe, and notably in the track of the great ocean-currents, where marine life is so abundant, various kinds of coral take root upon the edges and summits of submerged ridges and peaks, as well as on the shelving sea-bottom facing continents or encircling islands. These creatures do not appear to flourish at a greater depth than 15 or 20 fathoms, and they are killed by exposure to sun and air. The vertical space within which they live may therefore be stated broadly as about 100 feet. They grow in colonies, each composed of many individuals, but all united into one mass, which at first may be merely a little solitary clump on the sea-floor, but which, as it grows, joins other similar clumps to form what is known as a reef.

Each individual secretes from the sea-water a hard calcareous skeleton inside its transparent jelly-like body, and when it dies, this skeleton forms part of the platform upon which the next generation starts. Thus the reef is gradually built upward as a mass of calcareous rock, though only its upper surface is covered with living corals. These creatures continue to work upward until they reach low-water mark, and then their further upward progress is checked. But they are still able to grow outward. On the outer edges of the reef they flourish most vigorously, for there, amid the play of the breakers, they find the food that is brought to them by the ocean-currents. From time to time fragments are torn off by breakers from the reef and roll down its steep front. There, partly by the chemical

action of the sea-water, and partly by the fine calcareous mud and sand, produced by the grinding action of the waves and washed into their crevices, these loose blocks are cemented into a firm, steep slope, on the top of which the reef continues to grow outwards. Blocks of coral and quantities of coral-sand are also thrown up on the surface of the reef, where by degrees they form a belt of low land above the reach of the waves. On the inside of the reef, where the corals cannot find the abundant food-supply afforded by the open water outside, they dwindle and die. Thus the tendency of all reefs must be to grow seawards, and to increase in breadth. Perhaps their breadth may afford some indication of their relative age.

Where a reef has started on a shelving sea-bottom near the coast of a continent, or round a volcanic island, the space of water inside is termed the lagoon channel. Where the reef has been built up on some submarine ridge or peak, and there is consequently no land inside, the enclosed space of water is called a lagoon, and the circular reef of coral is known as an atoll. If no subsidence of the sea-bottom takes place, the maximum thickness of a reef must be limited by the space within which the corals can thrive—that is, a vertical depth of about 100 feet from the surface of the sea. But the effect of the destruction of the ocean-front of the reef, and the piling up of a slope of its fragments on the sea-bottom outside, will be to furnish a platform of the same materials on which the reef itself may grow outward, so that the united mass of calcareous rock may attain a very much greater thickness than 100 feet. On the other hand, if the sea-bottom were to sink at so slow a rate that the reef-building corals could keep pace with the subsidence, a mass of calcareous rock many thousand feet thick might obviously be formed by them. It is a disputed question in which of these two ways atolls have been formed.

It is remarkable how rapidly and completely the structure of the coral-skeleton is effaced from the coral-rock, and a more or less crystalline and compact texture is put in its place. The change is brought about partly by the action of both sea-water and rain-water in dissolving and re-depositing carbonate of lime among the minute interstices of the rock, and partly also by

the abundant mud and sand produced by the pounding action of the breakers on a reef, and washed into the crevices. On the portion of a reef laid dry at low water, the coral-rock looks in many places as solid and old as some of the ancient white limestones and marbles of the land. There, in pools where a current or ripple of water keeps the grains of coral-sand in motion, each grain may be seen to have taken a spherical form unlike that of the ordinary irregularly rounded or angular particles. This arises because carbonate of lime in solution in the water is deposited round each grain as it moves along. A mass of such grains aggregated together is called oölite, from its resemblance to fish-roe. In many limestones, now forming wide tracts of richly cultivated country, this oölitic structure is strikingly exhibited. There can be no doubt that in these cases it was produced in a similar way to that now in progress on coral reefs.

In the coral tracts of the Pacific Ocean there are nearly 300 coral islands, besides extensive reefs round volcanic islands. Others occur in the Indian Ocean. Coral reefs abound in the West Indian seas, where, on many of the islands, they have been upraised into dry land, in Cuba to a height of 1,100 feet above sea-level. The Great Barrier Reef that fronts the northeastern coast of Australia is 1,250 miles long, and from 10 to 90 miles broad.

There are other ways in which the aggregation of animal remains forms more or less extensive and durable rocks. Many interesting volumes have been written on the subject, but enough has been said here to show that by the accumulation of their hard parts animals leave permanent records of their presence both on land and in the sea.

II. *Preservation of Remains of Plants and Animals in Sedimentary Deposits.*—But it is not only in rocks formed out of their remains that living things leave their enduring records. These remains may be preserved in almost every kind of deposit, under the most wonderful variety of conditions. And as it is in large measure from their occurrence in such deposits that the geologist derives the evidence that successive tribes of plants and animals have peopled the globe, and that the climate and geography of the earth have greatly varied at different periods, we

shall find it useful to observe the different ways in which the remains both of plants and animals are at this moment being entombed and preserved upon the land and in the sea. With the knowledge thus gained, it will be easier to understand the lessons taught by the organic remains that lie among the various solid rocks around us.

It is evident that in the vast majority of cases, the plants and animals of the land leave no perceptible trace of their presence. Of the forests that once covered so much of central and northern Europe, which is now bare ground, most have disappeared, and unless authentic history told that they had once flourished, we should never have known anything about them. There were also herds of wild oxen, bears, wolves, and other denizens contemporaneous with the vanished forests. But they too have passed away, and we might ransack the soil in vain for any trace of them.

If the remains of terrestrial vegetation and animals are anywhere preserved it must obviously be only locally, but the favorable circumstances for their preservation, although not everywhere to be found, do present themselves in many places if we seek for them. The fundamental condition is that the relics should, as soon as possible after death, be so covered up as to be protected from the air and from too rapid decomposition. Where this condition is fulfilled, the more durable of them may be preserved for an indefinite series of ages.

On the land there are various places where the remains both of plants and animals are buried and shielded from decay. To some of these reference has already been made. Thus amid the fine silt, mud, and marl gathering on the floors of lakes, leaves, fruits, and branches, or tree-trunks, washed from the neighboring shores, may be imbedded, together with insects, birds, fishes, lizards, frogs, field-mice, rabbits, and other inhabitants. These remains may of course often decay on the lake-bottom, but where they sink into or are quickly covered up by the sediment, they may be effectually preserved from obliteration. They undergo a change, indeed, being gradually turned into stone. But this conversion may be effected so gently as to retain the finest microscopic textures of the original organisms.

In peat-bogs also, as stated elsewhere, wild animals are often engulfed, and their soft parts occasionally preserved as well as their skeletons. The deltas of river-mouths must receive abundantly the remains of animals swept off by floods. As the carcasses float seawards, they begin to fall to pieces and the separate bones sink to the bottom, where they are soon buried in the silt. Among the first bones to separate from the rest of the skeleton are the lower jaws. We should therefore expect that in excavations made in a delta these bones would occur most frequently. The rest of the skeleton is apt to be carried farther out to sea before it can find its way to the bottom. The stalagmite floor of caverns is an admirable material for enclosing and preserving organic remains. The animals that fell into these recesses, or used them as dens in which they lived or into which they dragged their prey, have left their bones on the floors, where encased in or covered by solid stalagmite, these relics have remained for ages. Most of our knowledge of the animals which inhabited Europe at the time when man appeared, is derived from the materials disinterred from these bone-caves. We may also refer here to the travertine formed by mineral-springs and to the facility with which leaves, shells, insects, and small birds, reptiles, or mammals may be enclosed and preserved in travertine. Thus, while the plants and animals of the land for the most part die and decay into mere mould, there are here and there localities where their remains are covered up from decay and preserved as memorials of the life of the time.

On the bottom of the sea the conditions for the preservation of organic remains are more general and favorable than on land. Among the sands and gravels of the shore, some of the stronger shells that live in the shallower waters near land may be covered up and preserved, though often only in rolled fragments. It is below tide-mark, however, and more especially beneath the limit to which the disturbing action of breakers descends, that the remains of the denizens of the sea are most likely to be buried in sediment and to be preserved there as memorials of the life of the sea. It is evident that hard and therefore durable relics have the best chance of escaping destruction. Shells, corals, corallines, spicules of sponges, teeth, vertebræ,

and ear-bones of fishes may be securely entombed in successive layers of silt or mud. But the vast crowds of marine creatures that have no hard parts must always perish without leaving any trace whatever of their existence. And even in the case of those which possess hard shells or skeletons, it will be easily understood that the great majority of them must be decomposed upon the sea-bottom, their component elements passing back again into the sea-water from which they were originally derived. It is only where sediment is deposited fast enough to cover them up and protect them before they have time to decay, that they may be expected to be preserved.

In the most favorable circumstances, therefore, only a very small proportion of the creatures living in the sea at any time leave a tangible record of their presence in the deposits of the sea-bottom. It is in the upper waters of the ocean, and especially in the neighborhood of land, that life is most abundant. The same region also is that in which the sediment derived from the waste of the land is chiefly distributed. Hence it is in these marginal parts of the ocean that the conditions for preserving memorials of the animals that inhabit the sea are best developed.

As we recede from the land, the rate of deposit of sediment on the sea-floor gradually diminishes, until in the central abysses it reaches that feeble stage so strikingly brought before us by the evidence of the manganese nodules. The larger and thinner calcareous organisms are attacked by the sea-water and dissolved, apparently before they can sink to the bottom; at least their remains are comparatively rarely found there. It is such indestructible objects as sharks' teeth and vertebræ and ear-bones of whales that form the most conspicuous organic relics in these abysmal deposits.

Summary.—Plants and animals leave their records in geological history, partly by forming distinct accumulations of their remains, partly by contributing their remains to be imbedded in different kinds of deposits both on land and in the sea. As examples of the first mode of chronicling their existence we may take the growth of marsh-plants in peat-bogs, the spread of mangrove-swamps along tropical shores, and the deposition

of infusorial earth on the bottom of lakes and of the sea; the accumulation of nullipore sand into solid stone, the formation of extensive shell-banks in many seas, the wide diffusion of organic ooze over the floor of the sea, and the growth of coral reefs. As illustrations of the second method, we may cite the manner in which the remains of terrestrial plants and animals are preserved in peat-bogs, in the deltas of rivers, in the stalagmite of caverns, and in the travertine of springs; and in the way in which the hard parts of marine creatures are entombed in the sediments of the sea-floor, more especially along that belt fringing the continents and islands, where the chief deposit of sediment from the disintegration of the land takes place. Nevertheless, alike on land and sea, the proportion of organic remains thus sealed up and preserved is probably always but an insignificant part of the total population of plants and animals living at any given moment.

EVOLUTION AND NATURE STUDIES

Wonders of Plant Life

By RICHARD KERR

THE MONKEY'S DINNER-BELL

WE are accustomed to noisy outbursts when we are in the neighborhood of certain juvenile representatives of the animal kingdom. Such outbursts we attribute to "animal spirits"—and, unfortunately, we know too frequently many noisy results to proceed from the use of "vegetable spirits," or spirits extracted from certain plants; but we are wholly unprepared for noisy and obstreperous conduct on the part of the plants themselves.

Trees and their allies behave themselves in a becoming manner. To us they are models of steady, decorous conduct.

This exemplary behavior, which is the general rule at home, leads one to the deceptive idea that the trees of other parts of the world are endowed with the same self-respect. But this is far from being the case.

Certain trees of the West Indies and of the tropical parts of South America instead of being circumspect, at certain seasons of the year seem to revel in playing pranks not only upon the natives, but also upon the monkeys that honor them with denizenship.

When trees are given to frivolity an allowance must be made for the comic antics of the monkeys of the New World.

It will be seen from the following that some idea of the natural laws prevailing among certain species of trees in the west may be obtained without journeying across the Atlantic.

A few winters ago a gentleman received a consignment of

vegetable curiosities from a relative in British Guiana. Among the number was a sand-box nut, botanically known as *Hura crepitans*.

Not a word was said about the proclivities of these nuts. Perhaps it was just as well. It may have been better for his education that he was left in ignorance. The nut itself would educate him. But education ought to be a gradual process. If the nuts thought at all, they thought otherwise.

This beautiful nut specimen, with fourteen compartments comprising its periphery, and with radiations forming an excellent design in geometry, was placed under a glass shade on the mantelpiece. It was frequently taken out, handled, admired, and its fourteen kernels rattled. It was then replaced side by side with other ornaments.

The owner was proud of his possession, for no one else in the town had one. The museum authorities could not boast of a single specimen.

I commend the curator for his respect for his glass cases, and for his care of the eyes of his clients.

For several months the nut was in high favor and was prized beyond most of the specimens in the collection of curios. There was no need, however, to prize it, for it had a peculiar way of prizing itself.

It was a harmless custom of the possessor to go round each night to fasten the windows and doors, and to see that everything was safe.

One night, while he was thus occupied, without any warning whatever, a loud report, quite up to that of any pistol, startled the whole house. He naturally thought he had been fired at through the window, and this surmise gained support owing to the shower of broken glass that followed the report.

The window was not broken, but the glass case was gone from the mantelpiece, and alas! the beautiful sand-box nut was gone as well.

He found the fourteen kernels and the various pieces that made up the lovely device, but "not all the king's horses, nor all the king's men" could build up the box-nut as it was, again.

At first the owner was sorry for his loss, but he had gained

information. The experience opened up in a moment the why and the wherefore of this startling explosion.

He could get more box-nuts from Guiana, and he resolved to take good care to prevent their apparent suicide.

It appears that the explosion is necessary for the protection of the trees.

Owing to this effort the kernels are scattered several yards away, and do not fall immediately under the trees, as would be the case if the pods opened gradually.

It requires no great stretch of imagination to see that if the seeds fell under the tree they would take root in the decayed tropical vegetation, would grow up, and would ultimately impoverish the parent tree. This, in time, would tend to the degeneracy of the species.

A general, who has spent several years in Jamaica, informs me that one of these trees, growing immediately in front of his quarters, was the source of some lively scenes during the ripening season.

Repeatedly were the fragments of the exploded nuts sent in through the windows.

The monkeys in the branches of *Hura crepitans* never seem to become reconciled to these explosions, for as soon as a report takes place they scamper away to the other side of the tree, only to be met with more reports and consequent terror. For this reason the nuts are called "The Monkey's Dinner-Bell."

If these trees could be influenced to grow here it might be an advantage to the farmers. One or two trees in a field would produce sufficient nuts to act as scarecrows.

It is worth notice that under favorable conditions all the compartments of each nut explode simultaneously. This arises from the equal drying up and contraction of the layers of the cell walls.

Sometimes the fragments and kernels are scattered to a distance of fifteen or sixteen yards away from the outermost limits of the tree.

In the largest of the museums in Kew Gardens the curator is well aware of the love of liberty inherent in the box-nut. One bottleful of specimens is preserved in a solution, thus preventing the drying and contracting process. Close by is a glass jar

containing dried specimens. These can scarcely burst asunder, because several strands of stout copper wire have been passed around the circumference, and several times across the nut.

We can form some idea of the pent-up force in each little nut when we see them bound with copper wire sufficiently strong to bind a man to a post.

With patience and care it is possible to remove all the kernels and to fill in all the cavities with lead. In this form they are used as paper weights.

Hura crepitans is a branching tree that attains to a height of forty feet. It is often planted in the neighborhood of houses, notwithstanding its surprising powers. This is owing to the abundance of its glossy, poplar-like leaves, which afford a splendid protection from the rays of a tropical sun.

Some of the violets explode, so do members of the balsam family, and a cress as well as a spurge. One plant allied to the mistletoe is able to throw its seeds right on to another tree. The squirting cucumber, if touched by an unwary person, is apt to discharge the contents right in the face. None of these, however, proceeds with such vigor and regularity of division as "The Monkey's Dinner-Bell." When we think of the hurry and decision with which the *Hura* gets rid of its offspring, we fall into a spirit of "philosophy," and wonder how it is that the cocoanut palm not only provides its seeds with an almost impenetrable covering, but drops them gently at its very own feet. This instance is exactly the opposite of the one already quoted, and affords a good example of the diverse plans and methods of nature.

The *Lecythus* and *Anagallis* also explode in order to liberate their clusters of seeds.

THE LACE-PLANT

There comes to every one who really loves nature a feeling of almost ecstatic delight when he sees for the first time one of her attractive products.

The lace-plant is one of these products which give rise in a very marked degree to these pleasant sensations. A piece of

bark is stripped off the branch, one end is opened out and opened out until you wonder how many more foliations are coming. You arrive at a stage when you find you have a layer or layers as thin as a sheet of note-paper; but it is still capable of division until it approaches the texture of very fine muslin.

The thin piece of bark can be separated into twenty or more layers, and then you have a light object that would do well for dusting furniture, but it would be a sacrilegious act to turn it to such a degrading purpose. It deserves a place with your most costly treasures, although its price in Jamaica was only a few cents.

The native women of the island are expert in carrying the opening process a step or two farther. They take out strand after strand of the fibre and dexterously work them into various articles for wear and for household ornamentation. The spinning of the thread that is necessary in other branches of lace manufacture is not required here, for nature produces the thread ready for use when once it is taken out from its fellow threads that conjointly make up the bark.

This lace-plant, to which botanists have given the name *Lagetta lintearia*, as we have seen, is covered with a bark that consists of concentric layers of fibres which interlace so wonderfully, that without any great effort each layer comes off like a piece of lace from a number of pieces of lace pressed together, as it were. It facilitates the removal of the thin foliations to soak the bark in water.

There is authority for saying that King Charles II. received as a present from the Governor of Jamaica a cravat, a frill, and a pair of ruffles made by the natives of this material; and, to this day, it is made into nets for the hair, caps, bonnets, veils, collars, and other articles of apparel. In fact, samples of several of these articles may be seen in the largest of the museums.

It must not be imagined that the lace-bark fibre is delicate and fragile, for it really possesses great strength, and is more durable than several fabrics produced from spun thread. Sloane says that complete dresses for ladies have been made from this very bark, and that *Lagetta* cloth has been imported under the name of Guana.

Of course, the number of laminæ into which the bark is capable of division depends on the age of the tree, probably each foliation corresponds with a single year's growth.

With ordinary care all the manufactured products we have enumerated may be washed and bleached.

Unfortunately there was a time when this natural lace was turned to an ignoble purpose. It was used in the manufacture of thongs for whips, with which the negroes were beaten by their cruel taskmasters.

The lace-plant is often cultivated as an object of interest and curiosity. We must not leave the subject at this point without a few particulars as to its botanical qualifications. It is a small tree of the Spurge Laurel kind. The name given to the family is not much of an improvement upon any of the other names in favor with botanists—viz., the *Thymalæceæ*. It is known by its "perfect flowers," so we are told. For my part, I thought all flowers were perfect, for even Solomon in all his glory was not arrayed like one of them. It has a tubular perianth beautifully colored, eight stamens, and a small, round, hairy fruit enclosed in the persistent base of the perianth. It grows on limestone rocks, and inserts its roots into the fissures. It has broad, rounded leaves, and its flowers are like those of the lily-of-the-valley.

This property of splitting up into leaves, resembling the leaves of a book, is not confined to the lace-bark, *Lagetta*. Quite a large number of trees produce bark which can be made into clothing. In tropical countries the natives frequently take advantage of this, and produce materials that have all the appearance of having passed through the loom.

Nowadays several kinds of bark are made into ropes, paper, etc. Any museum with a fair collection representing economic botany is bound to have specimens of bark used in such manufactures.

Beautiful lace work has been made by Irish women from the fibres of the nettle and of the convolvulus. But this opens up a wide domain of trees and small plants, cocoanuts, the flax-plant, and a host of other members of the vegetable kingdom, which by their fibres, husks, pods, or even their stems, contribute to man's

comfort by supplying the raw materials in a lavish and yet mysterious manner for the purpose of manufacture.

Among the strikingly beautiful things of the earth must be classed in a very prominent position the bark of the lace-plant, *Lagetta lintearia*.

THE TEASEL OR TEAZEL ("DIPSACUS")

The teazel can perform a duty which no machine, however delicate or accurate, can do half so well. The genius of the nineteenth century produced appliances innumerable and wonderful, both in time and labor-saving; but, so far, the teazel defies imitation and is incomparably superior to any machinery, whether American, German, or English. No machine has yet been invented to supplant it. If any man can make artificial teazels, having the same elasticity, flexibility, and other qualities as the fruit-heads of this plant and at a trifling cost, he can win a name and a fortune.

The dried, thorny fruit-heads of the teazel are in demand wherever cloth is manufactured. It is apparent, therefore, that enormous numbers are required. Many millions of them are used annually in England alone. The demand is so great that over twenty million teazel-heads have to be imported from the south of Europe, France, and Germany, to supplement those grown in the West of England.

In the factories the teazel-heads are methodically arranged upon cylinders which revolve over the cloth so that the hooks of the teazels come in contact with the cloth and raise a nap which is subsequently cut level.

Wire cards and various other toothed contrivances have been tried, but they are more or less unyielding when the slightest obstruction occurs in the cloth, and a rent is the result.

The teazel is more yielding and, if it could bring reasoning powers into play, we should say it is more considerate, and rather than wound the susceptibilities of the beautiful material it sacrifices one of its awns or hooks so that the cloth should not be torn. Self-sacrifice, if not always appreciated, has in the case of the teazel a high commercial value. It will be no easy task

for man to make a machine, however automatic, that will be endowed with this additional quality of self-abnegation.

When the purple flowers wither, the heads with portions of the stems attached are dried and assorted into sizes to suit customers. According to their quality and sizes, they are known as "kings," "queens," "buttons," etc.

The teasel grows in the south and west of England by the hedge-rows and on waste ground. The plant requires two years for perfect growth. Its whole surface is covered with prickles. The leaves grow in pairs, and are so united at their bases as to form a deep receptacle for holding water. It was owing to this cup-like structure that it was considered a thirsty plant. Hence its generic name, *Dipsacus*, from a Greek word signifying to be thirsty.

The *Dipsacus fullonum*, the Fuller's Teazel, is thought by botanists to be a variety of *D. sylvestris*, the common teasel, which grows in the south of England, Ireland, Central and South Europe, and parts of Asia. And the only apparent difference from *D. sylvestris* lies in the fact that the scales or thorns of the fruit-heads of *D. fullonum* are hooked instead of straight.

The teasel reminds us that we must not despise the unattractive in nature. There is hardly a plant more uninviting. Leaves, stems, and fruit-heads are all covered with sharp thorns, like so many fixed bayonets which appear to mean both defence and defiance; yet, in its usefulness to the manufacturer and consequently to almost everybody, for most of us require cloth, it stands unrivalled.

THE PITCHER-PLANT

The insect-catching plants are among the most wonderful representatives of the vegetable kingdom. They are not by any means limited to the use of pitchers in their modes of capturing insects. The *Dionæa* and the *Drosera* have no pitchers.

There are at least thirty species of *Nepenthes*, all of which have pitchers. Each pitcher has a lid, but the function of the lid is not to act like a trap by falling over the mouth of the pitcher. It acts as an attractive surface, both by its color and its honey

secretion. The lip is covered with large glands which also secrete honey, so that insects are led from the lid to the lip. The lip is curved inwards at the edge and downwards, thus preventing the return of any insect that enters the pitcher. The inner surface of the pitcher below the lip is slippery, and in some pitchers, as that of the *Sarracenia*, it is covered with hairs pointing downwards, presenting an impassable barrier to any insect's return.

A digestive fluid is always present in the pitcher. It is a secretion from the glands of the inner surface, and contains a gastric ferment analogous to that of the members of the animal kingdom. The plant thus captures insects, and digests and assimilates them. Analyses of this liquid and of that of the stomach of the animal show no appreciable difference. On this question of digestion a line of demarcation cannot be drawn between the animal and the plant, but it rather serves as a bridge connecting the two kingdoms.

The question naturally arises, in what manner does the accumulation of putrid matter arising from the dead bodies of insects arrive at the roots for nutritive purposes? I believe it was Lord Avebury who found in the *Dionæa* of North Carolina and in other plants, a channel leading directly from the leaf to a point over the roots, along which the products of digestion pass; and that this same great authority was further rewarded in his researches with the pitcher-plant, *Sarracenia*, to which I have just referred, in discovering the actual constructor of this remarkable channel.

Large numbers of flies are drowned in these pitchers, and form a putrescent mass, in which the grub of an insect finds abundant food for itself while it is furthering the digestive processes of the plant. The grub in time is ready for changing into the pupa stage, and sets about boring a hole through the plant, along which it is to escape to the earth. This channel remains, and whenever it rains, the accumulated products in the pitcher become sufficiently liquid to pass along it and on to the roots. It is worth noting that the insect makes the passage just before the flowering time of the plant arrives, when the plant most needs nourishment.

It is evident that the duty of the pitchers is to supply extra nourishment for the growth of the flower and fruit. In tropical climates they also help to reduce the number of insects.

VENUS'S FLY-TRAP

A plant which the great Charles Darwin says "is one of the most wonderful in the world" must be well worthy of our notice. Unfortunately it is not easy to obtain specimens for observation, as its home is limited, so far as we know, to the eastern part of North Carolina. But Canby in America, and Hooker, Darwin, Lord Avebury, and Burdon Sanderson in England, have given a great deal of time and attention to the study of this plant—with exhaustive experiments—and they have placed within our reach a vast amount of information about the *Dionæa*, all of which is intensely interesting and invaluable. One can hardly imagine that such a tiny plant should absorb the special attention of such great and learned authorities. Therefore, while appreciating their work, we ought to learn the main particulars, at least, of this important member of the vegetable kingdom. "The rapidity and force of its movements" place it in its unique position among other plants.

In the case of the *Drosera*, the captured insect, in the first instance, is held by a glutinous secretion and is gradually embraced by the tentacles or arms of the plant. But the behavior of the *Dionæa* contrasts with this, in that its movements are more like that of a rat-trap. At the end of each footstalk there is a two-lobed leaf, the lobes standing at rather less than a right angle to each other. It is between these lobes that the insects are captured. The edges of the lobes are prolonged into spines. "Three minute, pointed processes or filaments, placed triangularly, are projected from the upper surfaces of both lobes." These have been proved to be sensitive points, contact with which causes the lobes to close rapidly. These little pointed processes stand in such a position that, when the lobes close, they interlock. "The upper surface of the leaf is thickly covered, excepting towards the margins, with minute glands of a reddish or purplish color, the rest of the leaf being

green. They secrete, but only when excited by the absorption of certain matters."

When an insect touches the sensitive hairs, the lobes press quickly and closely together, the glands are brought into contact with the insect, and secretion commences. This secretion is acid, and contains a digestive ferment. The leaves remain closely shut for many days, and after expanding again are torpid. The power of digestion is limited; the leaves cannot digest more than two or three times in their life.

"*Dionæa* is looked upon as the most highly specialized of insectivorous plants, its sensitive hairs serving as organs of touch, its lobes for capture, and its glands for the consumption of its prey, while in the *Drosera* the tentacles effect all these ends."

THE HOP-PLANT

There are several curious and interesting particulars connected with the hop-plant which are well worth mentioning. Nature has not provided all plants with thick, rigid stems capable of giving them sufficient support to stand alone in the battle of life. A great number of them, not having inherent strength to be independent, require external support, and are known as *climbing plants*.

In dense forests and jungles plants with weak stems would fare badly as regards sunshine, were it not that they are endowed with special facilities for attaining to great heights. This is accomplished, too, by the expenditure of very little in the way of material and in a variety of ways.

Some are *twining* plants. The whole of the plant twines round the supporting agent. One of the most graceful of all twining plants is the hop. This plant in climbing round its support takes the same direction as the hands of a clock—describing a right-handed helix. It is provided with longitudinal rows of tiny hooks, which give support to the plant. These hooks render a great service, because, as the foliage increases and hop-heads appear, the upper part of the plant becomes heavy, so that something more than the delicate stem is re-

quired to enable the plant to reach the sunshine, and to attain to its full maturity and prolific condition. The important function, therefore, of those little hooks becomes apparent.

The growth movement of a climbing plant is called its nutation. Wherever the plant or its tendril touches the object on which it is climbing, the stimulus of contact causes the side away from the object to grow more rapidly than the other, and in this way the plant or its tendril commences to curve round its support. It appears from this that plants are sensitive to continued contact, and that they move in response to such stimulus. This constantly brings new surfaces into contact, and causes the twining of the plant or of its tendril. We cannot fail to notice at this point how very closely the plants approach by their sensitiveness the members of the animal kingdom. The sense of touch seems to be very much of the same nature in both kingdoms.

But to return to the hop. The hop has a perennial root and annual stems. The male and female flowers are generally on separate plants. The male flowers are in loose tufts, but those of the female are in dense catkins with membranous, irregularly developed leaves or bracts. The hops of commerce consist of the female flowers and seeds. Numerous little, yellow, shining, resinous grains are to be seen on the bracts, which give out an aromatic odor. They are known as lupulinic glands, and are believed to be the most active parts of the hops.

The hop possesses both tonic and hypnotic properties (that is, power of inducing sleep). Pillows stuffed with hops are sometimes used with success in cases of sleeplessness. From the brewer's point of view the plant possesses several qualities which make it valuable to him in the manufacture of beer. First, in malt liquors, hops exert a chemical influence that preserves them from turning sour by checking acetous fermentation. This quality renders the beer capable of being kept. Secondly, the tannin of the hops, by precipitating the albumen of the barley, clarifies the beer. Thirdly, they give an aromatic flavor to the beer. Then, fourthly, comes in the question of *headiness*. Owing to this property the brewer need not use so

much of his malt. But apart from the purposes of brewing, hops are often prescribed as a tonic. John Gerarde, a botanist, surgeon, and quaint writer of Queen Elizabeth's reign, says of this plant:

"The hop joyeth in a fat and fruitfull ground, also it groweth amongst briars and thornes about the borders of fields. The flowers are used to season beere or ale with, and too many do cause bitternesse thereof, and are ill for the head. The manifold vertues of hops do manifest argue the wholesomenesse of beere, for the hops rather make it a physicall drinke to keep the body in health, than an ordinary drinke for the quenching of our thirst."

We are not all likely to accept his statement that hops make the beer "a physicall drinke to keep the body in health," but we must agree with him that "too many do cause bitternesse thereof, and are ill for the head."

In the time of the Romans the hop was a garden plant, and the young shoots were eaten as we eat asparagus. It was first used in England for brewing purposes in the reign of Henry VIII. Its introduction quite supplanted the use of the tender shoots of the broom that were used to give the bitterness so much desired.

In the third year from the date of planting, the hop-plants grown from root sets come to perfection. The young shoots appear towards the end of April, and the plants are in full bloom and ready for picking towards the end of August. The hops are spread out in the oast houses, and dried on a strong hempen or hair network, which allows the free passage of hot air. The process of drying takes from twelve to twenty-four hours. When dried they are placed in the stove-room, where they are fumigated with the fumes of flowers of sulphur. They are then ready for packing in bales. This is accomplished by a screw-press.

Hop-poles varying in height from ten to twenty feet are used for supporting the hops. When the hops are ready for picking, the stems are cut through about a yard from the ground, and the poles are pulled up so that the hops may be readily picked off by hand.

In F. E. Hulme's beautiful work, "Art Studies from Nature,"

he chooses the hop-plant for a wonderfully graceful design, set in two overlapping equilateral triangles, in which he makes a number of hop-heads fit into three angles, alternately with hop-leaves occupying the three angles between. For purposes of ornamentation, either in wood, stone, or plaster, its adaptability is all that could be desired. He mentions that the capitals of Southwell Minster afford a practical example of what may be done in this direction.

With regard to the way in which a plant climbs around a support, we say the hop twines in the direction taken by the hands of a watch, and the convolvulus twines in an opposite direction. These statements are not so convincing as they may appear at first sight. What right and left twining means often gives rise to a great deal of argument. But the matter can be easily settled in the following manner: Place a watch on its back on the table, then put a walking-stick standing upright also on the table. Begin at the lower end to twine a piece of cord round the stick in the same direction as that taken by the hands of the watch. The cord will exactly represent the twining of the hop.

SCHUBERTIA GRANDIFLORA

The original home of this remarkable plant is Central America. It thrives, however, in other countries. It is a climbing plant and may be purchased for a few cents at any of the large nurseries. Its lovely white blossoms appear in July, and they depend so gracefully on their stalks that they remind one of bursting rockets. Every person who examines the details of the flower expresses astonishment as they are unfolded.

The plant is nearly four feet high, and its long twining stalk is covered with very fine hairs. Its white blossoms are quite two inches in diameter, and are frequently mistaken for those of the syringa. They yield a delicious perfume. But to come to the point of greatest interest for my purpose and one which might be looked upon as trivial and superficial by the learned botanist: Take a blossom and remove the five petals that form the corolla, and you will now have a bulb-shaped calyx attached

to its stalk. Proceed to fold back each sepal, and, on looking straight down upon the inner portion, a regular five-sided device appears with a raised center, having a close resemblance to a tiny ball of ivory not quite so large as a pea. To use an architect's phrase, we have so far been examining the *plan*. Let us look at its *elevation*. Hold it up and look at each corner of the pentagon, and at once the exact counterpart of the features of a venerable gentleman will be seen. Rotate it, and five similar faces will appear, the left eye of one face acting also as right eye for the next face. The top of the head is as smooth as the proverbial billiard ball, the forehead is wrinkled, the eyebrows are projecting, the eyes piercing from their sunken orbits, the nose prominent, the cheeks receding and lined, the long white beard is perfect, and the proportions of the head are apparently correct.

"Wonderful!" "lifelike!" and "startling!" are some of the exclamations of those who see this object for the first time.

The form of the human face is fairly well shown on the carapace of the "mask" crab and on other objects in nature, but this is not merely a case of one or two points of resemblance to a human head. It has all the appearance of a head proportionally reduced to very small dimensions.

Some one may say: "Explain the reason for all this." This is too much to expect. It is easier to ask questions about nature than to answer them. The aim in view in putting together brief descriptions of a series of curious products of nature is to draw attention to them and to cause an interest to be taken in them, in the hope that our readers may see that nature is stranger than fiction, and that they may find in nature ample material for absorbing research.

RIELLA

The riella is a graceful little water plant, spiral in form, and only two inches long. It is one of the mosses. The mosses are not generally looked upon as yielding any particular benefit to man. One writer says: "They perhaps yield fewer objects of utility to man than any other division of plants, except those

of the same alliance. In agriculture and in the garden, though of small size, they are often noxious weeds."

Surely the mosses make the landscape more beautiful, by affording a rich covering for old ruins and walls and trunks of trees. And do they not add largely to the material required for the formation of peat, and cannot peat be used in more than a hundred serviceable ways? Do they not collect and hold water in large quantities? This is to me a striking point in their favor, especially in warm climates. They seem to fulfil an unusually important office in the economy of nature. Mosses are to be found in all parts of the world, even on mountains, at heights where all other vegetation ceases, and in the depth of the forest where vegetation is most prolific. One of their functions is to collect the rainfall like so many sponges, and as they form a thick covering on the trees, they retain for them that moisture which would otherwise rush away in torrents.

Then again the disintegration of many rocks and the consequent formation of humus, or mold, is brought about by the action of mosses. The seeds of the higher plants, by taking root in this congenial mold, are thereby indebted to the despised mosses.

To the microscopist the mosses are always attractive for their marvelous structure and beauty.

The *riella*, although one of the mosses, is classed low down among the liverworts. In most liverworts the plant has a definite leafy structure, but in the *riella* we have an exception. Instead of leaves, it is endowed with a beautiful membranous wing about the fifth of an inch wide. This wing is of a pure green color and of extreme delicacy. It turns spirally on a central axis, forming a winding screw, and reminding one of the staircase up the tower of Exeter Cathedral. The central pillar in the staircase corresponds to the ribs or axis of the water-plant. As the membranous wing turns round it has the form of a cone inverted. Although the plant is only two inches high it is looked upon as one of the most remarkable in the whole of the vegetable kingdom.

All the mosses, with this single exception, grow horizontally, but the *riella* grows upright, and is one of the few that

grow in water. In fact, it comes to perfection completely under water.

It is attached to the ground by clasping roots known as *rhizoids*.

A distinguished soldier and botanist, Durieu de Maisonneuve, was the first to discover and describe this plant. He found it in Algiers.

The shape assumed by the plant is what is termed a right-handed helix. There are many instances of the spiral in nature.

EVOLUTION AND NATURE STUDIES

Training Elephants in Ceylon

By J. EMERSON TENNENT

AN impression prevails even to the present day that the process of training is tedious and difficult, and the reduction of a full-grown elephant to obedience, slow and troublesome in the extreme. In both particulars, however, the contrary is the truth. The training as it prevails in Ceylon is simple, and the conformity and obedience of the animal are developed with singular rapidity. For the first three days, or till they will eat freely, which they seldom do in a less time, the newly captured elephants are allowed to stand quiet; and, if practicable, a tame elephant is tied near to give the wild ones confidence. Where many elephants are being trained at once, it is customary to put every new captive between the stalls of half-tamed ones, when it soon takes to its food. This stage being attained, training commences by placing tame elephants on either side. The "corroowevidahn," or the head of the stables, stands in front of the wild elephants holding a long stick with a sharp iron point. Two men are then stationed one on either side, assisted by the tame elephants, and each holding a hendoo, or crook, towards the wild one's trunk, whilst one or two others rub their hands over his back, keeping up all the while a soothing and plaintive chant, interlarded with endearing epithets, such as "Ho! my son," or "Ho! my father," or "my mother," as may be applicable to the age and sex of the captive. The elephant is at first furious, and strikes in all directions with his trunk; but the men in front receiving all these blows on the points of their weapons, the extremity of the trunk



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TRAINED ELEPHANTS IN CEYLON.

becomes so sore that the animal curls it up close, and seldom afterwards attempts to use it offensively. The first dread of man's power being thus established, the process of taking him to bathe between two tame elephants is greatly facilitated, and by lengthening the neck rope, and drawing the feet together as close as possible, the process of laying him down in the water is finally accomplished by the keepers pressing the sharp point of their hendoos over the backbone.

For many days the roaring and resistance which attend the operation are considerable, and it often requires the sagacious interference of the tame elephants to control the refractory wild ones. It soon, however, becomes practicable to leave the latter alone, only taking them to and from the stall by the aid of a decoy. This step lasts, under ordinary treatment, for about three weeks, when an elephant may be taken alone with his legs hobbled, and a man walking backwards in front with the point of the hendoo always presented to the elephant's head, and a keeper with an iron crook at each ear. On getting into the water, the fear of being pricked on his tender back induces him to lie down directly on the crook being only held over him *in terrorem*. Once this point has been achieved, the further process of taming is dependent upon the disposition of the creature.

The greatest care is requisite, and daily medicines are applied, to heal the fearful wounds on the legs which even the softest ropes occasion. This is the great difficulty of training; for the wounds fester grievously, and months and sometimes years will elapse before an elephant will allow his feet to be touched without indications of alarm and anger.

The observation has been frequently made that the elephants most vicious and troublesome to tame, and the most worthless when tamed, are those distinguished by a thin trunk and flabby pendulous ears. The period of tuition does not appear to be influenced by the size or strength of the animals; some of the smallest give the greatest amount of trouble; whereas, in the instance of the two largest that have been taken in Ceylon within the last thirty years, both were docile in a remarkable degree. One in particular, which was caught and trained by Mr. Cripps, when government agent, in the Seven Korles, fed

from the hand the first night it was secured, and in a very few days evinced pleasure on being patted on the head. There is none so obstinate, not even a rogue, that may not, when kindly and patiently treated, be conciliated and reconciled.

The males are generally more unmanageable than the females, and in both an inclination to lie down to rest is regarded as a favorable symptom of approaching tractability, some of the most resolute having been known to stand for months together, even during sleep. Those which are the most obstinate and violent at first are the soonest and most effectually subdued, and generally prove permanently docile and submissive. But those which are sullen or morose, although they may provoke no chastisement by their viciousness, are always slower in being taught, and are rarely to be trusted in after life.

But whatever may be its natural gentleness and docility, the temper of an elephant is seldom to be implicitly relied on in a state of captivity and coercion. The most amenable are subject to occasional fits of stubbornness; and even after years of submission, irritability and resentment will unaccountably manifest themselves. It may be that the restraints and severer discipline of training have not been entirely forgotten; or that incidents which in ordinary health would be productive of no demonstration whatever, may lead, in moments of temporary illness, to fretfulness and anger. The knowledge of this infirmity led to the popular belief recorded by Phile, that the elephant had two hearts, under the respective influences of which it evinced ferocity or gentleness; subdued by the one to habitual tractability and obedience, but occasionally roused by the other to displays of rage and resistance.

In the process of taming, the presence of the tame ones can generally be dispensed with after two months, and the captive may then be ridden by the driver alone; and after three or four months he may be intrusted with labor, so far as regards docility; but it is undesirable, and even involves the risk of life, to work an elephant too soon; it has frequently happened that a valuable animal has lain down and died the first time it was tried in harness, from what the natives believe to be a "broken heart,"—certainly without any cause inferable from injury or previous

disease. It is observable, that till a captured elephant begins to relish food and grow fat upon it, he becomes so fretted by work that it kills him in an incredibly short space of time.

The first employment to which an elephant is put is to tread clay in a brick field, or to draw a wagon in double harness with a tame companion. But the work in which the display of sagacity renders his labors of the highest value, is that which involves the use of heavy materials; and hence in dragging and piling timber, or moving stones for the construction of retaining walls and the approaches to bridges, his services in an unopened country are of the utmost importance. When roads are to be constructed along the face of steep declivities, and the space is so contracted that risk is incurred either of the working elephant falling over the precipice or of rocks slipping down from above, not only are the measures to which he resorts the most judicious and reasonable that could be devised, but if urged by his keeper to adopt any other, he manifests a reluctance sufficient to show that he has balanced in his own mind the comparative advantages of each. An elephant appears on all occasions to comprehend the purpose and object that he is expected to promote, and hence he voluntarily executes a variety of details without any guidance whatever from his keeper. This is one characteristic in which this animal manifests a superiority over the horse; although his strength in proportion to his weight is not so great as that of the latter.

His minute motions when engrossed by such operations, the activity of his eye, and the earnestness of his attitudes can only be comprehended by being seen. In moving timber and masses of rock his trunk is the instrument on which he mainly relies, but those which have tusks turn them to good account. To get a weighty stone out of a hollow an elephant will kneel down so as to apply the pressure of his head to move it upwards, then steadying it with one foot till he can raise himself, he will apply a fold of his trunk to shift it to its place, and fit it accurately in position: this done, he will step round to view it on either side, and adjust it with due precision. He appears to gauge his task by his eye, and to form a judgment whether the weight be proportionate to his strength. If doubtful of his own power, he

hesitates and halts, and if urged against his will, he roars and shows temper.

In clearing an opening through forest land, the power of the African elephant and the strength ascribed to him by a recent traveler, as displayed in uprooting trees, have never been equaled or approached by anything I have seen of the elephant in Ceylon or heard of him in India. Of course much must depend on the nature of the timber and the moisture of the soil; thus a strong tree on the verge of a swamp may be overthrown with greater ease than a small and low one in parched and solid ground. I have seen no "tree" deserving the name, nothing but jungle and brushwood, thrown down by the mere movement of an elephant without some special exertion of force. But he is by no means fond of gratuitously tasking his strength; and food being so abundant that he obtains it without an effort, it is not altogether apparent, even were he able to do so, why he should assail "the largest trees in the forest," and encumber his own haunts with their broken stems; especially as there is scarcely anything which an elephant dislikes more than venturing amongst fallen timber.

A tree of twelve inches in diameter resisted successfully the most strenuous struggles of the largest elephant I ever saw led to it; and when directed by their keepers to clear away jungle, the removal of even a small tree, or a healthy young cocoanut palm, is a matter of both time and exertion. Hence the services of an elephant are of much less value in clearing a forest than in dragging and piling felled timber. But in the latter occupation he manifests an intelligence and dexterity which is surprising to a stranger, because the sameness of the operation enables the animal to go on for hours disposing of log after log, almost without a hint or direction from his attendant. For example, two elephants employed in piling ebony and satinwood in the yards attached to the commissariat stores at Colombo, were so accustomed to their work that they were able to accomplish it with equal precision and with greater rapidity than if it had been done by dock laborers. When the pile attained a certain height, and they were no longer able by their conjoint efforts to raise one of the heavy logs of ebony to the

summit, they had been taught to lean two pieces against the heap, up the inclined plane of which they gently rolled the remaining logs, and placed them trimly on the top.

It has been asserted that in their occupations "elephants are to a surprising extent the creatures of habit," that their movements are altogether mechanical, and that "they are annoyed by any deviation from their accustomed practice, and resent any constrained departure from the regularity of their course." So far as my own observation goes, this is incorrect; and I am assured by officers of experience that, in regard to changing his treatment, his hours, or his occupation, an elephant evinces no more consideration than a horse, but exhibits the same pliancy and facility.

At one point, however, the utility of the elephant stops short. Such is the intelligence and earnestness he displays in work, which he seems to conduct almost without supervision, that it has been assumed that he would continue his labor, and accomplish his given task, as well in the absence of his keeper as during his presence. But here his innate love of ease displays itself, and if the eye of his attendant be withdrawn, the moment he has finished the thing immediately in hand, he will stroll away lazily, to browse or enjoy the luxury of fanning himself and blowing dust over his back.

The means of punishing so powerful an animal is a question of difficulty to his attendants. Force being almost inapplicable, they try to work on his passions and feelings, by such expedients as altering the nature of his food or withholding it altogether for a time. On such occasions the demeanor of the creature will sometimes evince a sense of humiliation as well as of discontent. In some parts of India it is customary, in dealing with offenders, to stop their allowance of sugar canes or of jaggery; or to restrain them from eating their own share of fodder and leaves till their companions shall have finished; and in such cases the consciousness of degradation betrayed by the looks and attitudes of the culprit is quite sufficient to identify him, and to excite a feeling of sympathy and pity.

The elephant's obedience to his keeper is the result of affection, as well as of fear; and although his attachment be-

comes so strong that an elephant in Ceylon has been known to remain out all night, without food, rather than abandon his mahout, lying intoxicated in the jungle, yet he manifests little difficulty in yielding the same submission to a new driver in the event of a change of attendants. This is opposed to the popular belief that "the elephant cherishes such an enduring remembrance of his old mahout, that he cannot easily be brought to obey a stranger." In the extensive establishments of the Ceylon government, the keepers are changed without hesitation, and the animals, when equally kindly treated, are usually found to be as tractable and obedient to their new driver as to the old, in fact so soon as they have become familiarized with his voice.

This is not, however, invariably the case; and Mr. Cripps, who had remarkable opportunities for observing the habits of the elephant in Ceylon, mentioned to me an instance in which one of a singularly stubborn disposition occasioned some inconvenience after the death of its keeper, by refusing to obey any other, till its attendants bethought them of a child about twelve years old, in a distant village, where the animal had been formerly picketed, and to whom it had displayed much attachment. The child was sent for; and on its arrival the elephant, as anticipated, manifested extreme satisfaction, and was managed with ease, till by degrees it became reconciled to the presence of a new superintendent.

It has been said that the mahouts die young, owing to some supposed injury to the spinal column from the peculiar motion of the elephant; but this remark does not apply to those in Ceylon, who are healthy, and as long-lived as other men. If the motion of the elephant be thus injurious, that of the camel must be more so; yet we never hear of early death ascribed to this cause by the Arabs.

The voice of the keeper, with a very limited vocabulary of articulate sounds, serves almost alone to guide the elephant in his domestic occupations. Sir Everard Home, from an examination of the muscular fibres in the drum of an elephant's ear, came to the conclusion that notwithstanding the distinctness and power of his perception of sounds at a greater distance

than other animals, he was insensible to their harmonious modulation and destitute of a musical ear. But Professor Harrison, in a paper read before the Royal Irish Academy in 1847, has stated that on a careful examination of the head of an elephant which he had dissected, he could "see no evidence of the muscular structure of the *membrana tympani* so accurately described by Sir E. Home." Sir Everard's deduction, I may observe, is clearly inconsistent with the fact that the power of two elephants may be combined by singing to them a measured chant, somewhat resembling a sailor's capstan song; and in labor of a particular kind, such as hauling a stone with ropes, they will thus move conjointly a weight to which their divided strength would be unequal.

Nothing can more strongly exhibit the impulse to obedience in the elephant than the patience with which, at the order of his keeper, he swallows the nauseous medicines of the native elephant doctors; and it is impossible to witness the fortitude with which (without shrinking) he submits to excruciating surgical operations for the removal of tumors and ulcers to which he is subject, without conceiving a vivid impression of his gentleness and intelligence. Dr. Davy, when in Ceylon, was consulted about an elephant in the government stud which was suffering from a deep, burrowing sore in the back, just over the backbone, which had long resisted the treatment ordinarily employed. He recommended the use of the knife, that issue might be given to the accumulated matter, but no one of the attendants was competent to undertake the operation. "Being assured," he continues, "that the creature would behave well, I undertook it myself. The elephant was not bound, but was made to kneel down at his keeper's command, and with an amputating knife, using all my force, I made the incision required through the tough integuments. The elephant did not flinch, but rather inclined towards me when using the knife; and merely uttered a low, and as it were suppressed, groan. In short, he behaved as like a human being as possible, as if conscious (as I believe he was), that the operation was for his good, and the pain unavoidable."

Obedience to the orders of his keepers is not, however,

to be assumed as the result of a uniform perception of the object to be attained by compliance; and we cannot but remember the touching incident which took place during the slaughter of the elephant at Exeter Change in 1846, when, after receiving ineffectually upwards of one hundred and twenty balls in various parts of his body, he turned his face to his assailants on hearing the voice of his keeper, and knelt down at the accustomed word of command, so as to bring his forehead within view of the rifles.

EVOLUTION AND NATURE STUDIES

The Pitch Lake in the West Indies

By CHARLES KINGSLEY

AS we neared the shore, we perceived that the beach was black with pitch; and the breeze being off the land, the asphalt smell (not unpleasant) came off to welcome us. We rowed in, and saw in front of a little row of wooden houses, a tall mulatto, in blue policeman's dress, gesticulating and shouting to us. He was the ward policeman, and I found him (as I did all the colored police) able and courteous, shrewd and trusty. These police are excellent specimens of what can be made of the negro, or half-negro, if he be but first drilled, and then given a responsibility which calls out his self-respect. He was warning our crew not to run aground on one or other of the pitch reefs, which here take the place of rocks. A large one, a hundred yards off on the left, had been almost all dug away, and carried to New York or to Paris to make asphalt-pavement.

The boat was run ashore, under his directions, on a spit of sand between the pitch; and when she ceased bumping up and down in the muddy surf, we scrambled out into a world exactly the hue of its inhabitants of every shade, from jet black to copper-brown. The pebbles on the shore were pitch. A tide-pool close by was enclosed in pitch; a four-eyes was swimming about in it, staring up at us; and when we hunted him, tried to escape, not by diving, but by jumping on shore on the pitch, and scrambling off between our legs. While the policeman, after profoundest courtesies, was gone to get a mule-cart to take us up to the lake, and planks to bridge its water channels, we took a look round at this oddest of corners of the earth.

In front of us was the unit of civilization,—the police-station, wooden, on wooden stilts (as all well-built houses are here), to insure a draught of air beneath them. We were, of course, asked to come in and sit down, but preferred looking about, under our umbrellas; for the heat was intense. The soil is half pitch, half brown earth, among which the pitch sweals in and out as tallow sweals from a candle. It is always in slow motion under the heat of the tropic sun; and no wonder if some of the cottages have sunk right and left in such a treacherous foundation. A stone or brick house could not stand here; but wood and palm-thatch are both light and tough enough to be safe, let the ground give way as it will.

The soil, however, is very rich. The pitch certainly does not injure vegetation, though plants will not grow actually in it. The first plants which caught our eyes were pineapples, for which La Brea is famous. The heat of the soil, as well as the air, brings them to special perfection. They grow about anywhere, unprotected by hedge or fence; for the negroes here seem honest enough, at least toward each other; and at the corner of the house was a bush worth looking at, for we had heard of it for many a year. It bore prickly, heart-shaped pods an inch long, filled with seeds coated with a red waxy pulp.

This was a famous plant—*Bixa orellana Roucou*; and that pulp was the well-known annatto dye of commerce. In England and Holland it is used merely, I believe, to color cheeses, but in the Spanish Main to color human beings. The Indian of the Orinoco prefers paint to clothes; and when he has “roucoued” himself from head to foot, considers himself in full dress, whether for war or dancing. Doubtless he knows his own business best from long experience. Indeed, as we stood broiling on the shore, we began somewhat to regret that European manners and customs prevented our adopting the Guaraon and Arrawak fashion.

The mule-cart arrived; the lady of the party was put into it on a chair, and slowly bumped and rattled past the corner of Dundonald Street—so named after the old sea-hero, who was, in his life-time, full of projects for utilizing this same pitch—and up in pitch road, with a pitch gutter on each side.

The pitch in the road has been, most of it, laid down by hand, and is slowly working down the slight incline, leaving pools and ruts full of water, often invisible, because covered with a film of brown pitch-dust, and so letting in the unwary walker over his shoes. The pitch in the gutter-bank is in its native place, and as it spues slowly out of the soil into the ditch in odd wreaths and lumps, we could watch, in little, the process which has produced the whole deposit—probably the whole lake itself.

A bullock-cart, laden with pitch, came jolting down past us, and we observed that the lumps, when the fracture is fresh, have all a drawn out look; that the very air bubbles in them, which are often very numerous, are all drawn out likewise, long and oval, like the air-bubbles in some ductile lavas.

On our left, as we went on, the bush was low, all of yellow cassia and white *Hibiscus*, and tangled with lovely convolvulus-like creepers, *Ipomoea* and *Echites*, with white, purple or yellow flowers. On the right were negro huts and gardens, fewer and fewer as we went on,—all rich with fruit trees, especially with oranges, hung with fruit of every hue; and beneath them, of course, the pineapples of La Brea. Everywhere along the road grew, seemingly wild here, that pretty low tree, cashew, with rounded yellow-veined leaves and little green flowers, followed by a quaint pink and red-striped pear, from which hangs, at the larger and lower end, a kidney-shaped bean, which bold folk eat when roasted; but woe to those who try it when raw; for the acrid oil blisters the lips, and even while the beans are roasting the fumes of the oil will blister the cook's face if she holds it too near the fire.

As we went onward up the gentle slope (the rise is one hundred and thirty-eight feet in rather more than a mile), the ground became more and more full of pitch, and the vegetation poorer and more rushy, till it resembled, on the whole, that of an English fen. An *Ipomoea* or two, and a scarlet flowered dwarf *Heliconia*, kept up the tropic type, as does a stiff brittle fern about two feet high. We picked the weeds, which looked like English mint or basil, and found that most of them had three longitudinal nerves in each leaf, and were

really *Melastomas*, though dwarfed into a far meaner habit than that of the noble forms we saw at Chaguanas, and again on the other side of the lake. On the right, too, in a hollow, was a whole wood of Groogroo palms, gray stemmed, gray leaved, and here and there a patch of white or black *Roseau* rose gracefully eight or ten feet high among the reeds.

The plateau of pitch now widened out, and the whole ground looked like an asphalt pavement, half overgrown with marsh-loving weeds, whose roots feed in the sloppy water which overlies the pitch. But, as yet, there was no sign of the lake. The incline, though gentle, shuts off the view of what is beyond. This last lip of the lake has surely overflowed, and is overflowing still, though very slowly. Its furrows all curve downward; and it is, in fact, as one of our party said, "a black glacier." The pitch, expanding under the burning sun of day, must needs expand most toward the line of least resistance—that is, downhill; and when it contracts again under the coolness of night, it contracts, surely, from the same cause, more downhill than uphill; and so each particle never returns to the spot whence it started, but rather drags the particles above it downward toward itself. At least, so it seemed to us. Thus may be explained the common mistake which is noticed by Messrs. Wall and Sawkins in their admirable description of the lake.

"All previous descriptions refer the bituminous matter scattered over the La Brea district, and especially that between the village and the lake, to streams which have issued at some former epoch from the lake, and extended into the sea. This supposition is totally incorrect, as solidification would probably have ensued before it had proceeded one-tenth of the distance; and such of the asphalt as has undoubtedly escaped from the lake has not advanced more than a few yards, and always presents the curved surfaces already described, and never appears as an extended sheet."

Agreeing with this statement as a whole, I nevertheless cannot but think it probable that a great deal of the asphalt, whether it be in large masses or in scattered veins, may be moving very slowly down hill, from the lake to the sea, by the process of expansion by day and contraction by night, and may

be likened to a caterpillar, or rather caterpillars innumerable, progressing by expanding and contracting their rings, having strength enough to crawl down hill, but not strength enough to back up hill again.

At last we surmounted the last rise, and before us lay the famous lake—not at the bottom of a depression, as we expected, but at the top of a rise, whence the ground slopes away from it on two sides, and rises from it very slightly on the two others. The black pool glared and glittered in the sun. A group of islands, some twenty yards wide, were scattered about the middle of it. Beyond it rose a double forest of Moriche fan-palms; and to the right of them high wood with giant Mombins and undergrowth of Cocorite—a paradise on the other side of the Stygian pool.

We walked, with some misgivings, on to the asphalt, and found it perfectly hard. In a few steps we were stopped by a channel of clear water, with tiny fish and water-beetles in it; and, looking round, saw that the whole lake was intersected with channels, so unlike anything which can be seen elsewhere that it is not easy to describe them.

Conceive a crowd of mushrooms, of all shapes, from ten to fifty feet across, close together side by side, their tops being kept at exactly the same level, their rounded rims squeezed tight against each other; then conceive water poured on them so as to fill the parting seams, and in the wet season, during which we visited it, to overflow the tops somewhat. Thus would each mushroom represent, tolerably well, one of the innumerable flat asphalt bosses, which seem to have sprung up each from a separate center, while the parting seams would be of much the same shape as those in the asphalt, broad and shallow atop, and rolling downward in a smooth curve, till they are at bottom mere cracks from two to ten feet deep. Whether these cracks actually close up below, and the two contiguous masses of pitch become one, cannot be seen. As far as the eye goes down, they are two, though pressed close to each other. Messrs. Wall and Sawkins explain the odd fact clearly and simply. The oil, they say, which the asphalt contains when it rises first, evaporates in the sun, of course most on the outside of the

heap, leaving a thorough coat of asphalt, which has, generally, no power to unite with the corresponding coat of the next mass. Meanwhile Mr. Manross, an American gentleman, who has written a very clever and interesting account of the lake, seems to have been so far deceived by the curved and squeezed edges of these masses that he attributes to each of them a revolving motion, and supposes that the material is continually passing from the center to the edges, when it "rolls under," and rises again in the middle. Certainly the strange stuff looks, at the first glance, as if it were behaving in this way; and certainly, also, his theory would explain the appearance of sticks and logs in the pitch. But Messrs. Wall and Sawkins say that they have observed no such motion: nor did we; and I agree with them, that it is not very obvious to what force, or what influence, it could be attributable. We must, therefore, seek some other way of accounting for the sticks—which utterly puzzled us, and which Mr. Manross well describes as "numerous pieces of wood, which, being involved in the pitch, are constantly coming to the surface. They are often several feet in length, and five or six inches in diameter. On reaching the surface they generally assume an upright position, one end being detained in the pitch, while the other is elevated by the lifting of the middle. They may be seen at frequent intervals over the lake, standing up to the height of two or even three feet. They look like stumps of trees protruding through the pitch; but their parvenu character is curiously betrayed by a ragged cap of pitch which invariably covers the top, and hangs down like hounds' ears on either side."

Whence do they come? Have they been blown on to the lake, or left behind by man? or are they fossil trees, integral parts of the vegetable stratum below which is continually rolling upward? or are they of both kinds? I do not know. Only this is certain, as Messrs. Wall and Sawkins have pointed out, that not only "the purer varieties of asphalt, such as approach or are identical with asphalt glance, have been observed" (though not, I think, in the lake itself) "in isolated masses, where there was little doubt of their proceeding from ligneous substances of larger dimensions, such as roots and pieces of

trunks and branches," but, moreover, that "it is also necessary to admit a species of conversion by contact, since pieces of wood included accidentally in the asphalt, for example, by dropping from overhanging vegetation, are often found partially transformed into the material." This is a statement which we verified again and again, as we did the one which follows, namely, that the hollow bubbles which abound on the surface of the pitch "generally contain traces of the lighter portion of vegetation," and "are manifestly derived from leaves, etc., which are blown about the lake by the wind, and are covered with asphalt, and, as they become asphalt themselves, give off gases which form bubbles round them."

But how is it that those logs stand up out of the asphalt, with asphalt caps and hounds' ears (as Mr. Manross well phrases it) on the tops of them?

We pushed on across the lake, over the planks which the negroes laid down from island to island. Some, meanwhile, preferred a steeple-chase with water-jumps, after the fashion of the midshipmen on a certain second visit to the lake. How the negroes grinned delight and surprise at the vagaries of English lads—a species of animal altogether new to them; and how they grinned still more when certain staid and portly dignitaries caught the infection, and proved by more than one good leap that they too had been English school-boys—alas! long, long ago.

So, whether by bridging, leaping, or wading, we arrived at the little islands, and found them covered with a thick, low scrub; deep sedge, and among them pinguins, like huge pine-apples without the apple; gray wild-pines, parasites on Matapalos, which, of course, have established themselves, like robbers and vagrants as they are, everywhere; a true holly, with box-like leaves; and a rare cocoa-plum, very like the holly in habit, which seems to be all but confined to these little patches of red earth, afloat on the pitch. Out of the scrub, when we were there, flew off two or three night-jars, very like our English species, save that they had white in the wings; and on the second visit one of the midshipmen, true to the English boy's bird's-nesting instinct, found one of their eggs, white-spotted, in a grass nest.

Passing these little islands, which are said (I know not how truly) to change their places and number, we came to the very fountains of Styx, to that part of the lake where the asphalt is still oozing up.

As the wind set toward us, we soon became aware of an evil smell—petroleum and sulphureted hydrogen at once—which gave some of us a headache. The pitch here is yellow and white with sulphur foam; so are the water-channels; and out of both water and pitch innumerable bubbles of gas arise, loathsome to the smell. We became aware that the pitch was soft under our feet. We left the impression of our boots; and if we had stood still awhile, we should soon have been ankle-deep. No doubt there are spots where, if a man stayed long enough, he would be slowly and horribly engulfed. "But," as Mr. Manross says truly, "in no place is it possible to form those bowl-like depressions round the observer described by former travelers." What we did see is that the fresh pitch oozes out at the lines of least resistance, namely, in the channels between the older and more hardened masses, usually at the upper ends of them, so that one may stand on pitch comparatively hard, and put one's hand into pitch quite liquid, which is flowing softly out, like some ugly fungoid growth, such as may be seen in old wine-cellars, into the water. One such pitch-fungus had grown several yards in length in the three weeks between our first and second visit; and on another, some of our party performed exactly the same feat as Mr. Manross.

"In one of the star-shaped pools of water, some five feet deep, a column of pitch had been forced perpendicularly up from the bottom. On reaching the surface of the water it had formed a sort of center-table, about four feet in diameter, but without touching the sides of the pool. The stem was about a foot in diameter. I leaped out on this table, and found that it not only sustained my weight, but that the elasticity of the stem enabled me to rock it from side to side. Pieces torn from the edges of this table sank readily, showing that it had been raised by pressure, and not by its buoyancy."

True, though strange; but stranger still did it seem to us when we did at last what the negroes asked us, and dipped our

hands into the liquid pitch, to find that it did not soil the fingers. The old proverb that one cannot touch pitch without being defiled happily does not stand true here, or the place would be intolerably loathsome. It can be scraped up, moulded into any shape you will, wound in a string (as was done by one of the midshipmen) round a stick, and carried off; but nothing is left on the hand save clean, gray mud and water. It may be kneaded for an hour before the mud be sufficiently driven out of it to make it sticky. This very abundance of earthy matter it is which, while it keeps the pitch from soiling, makes it far less valuable than it would be were it pure.

It is easy to understand whence this earthy matter (twenty or thirty per cent.) comes. Throughout the neighborhood the ground is full, to the depth of hundreds of feet, of coaly and asphaltic matter. Layers of sandstone or of shale containing this decayed vegetable alternate with layers which contain none; and if, as seems probable, the coaly matter is continually changing into asphalt and oil, and then working its way upward through every crack and pore, to escape from the enormous pressure of the superincumbent soil, it must needs carry up with it innumerable particles of the soils through which it passes.

In five minutes we had seen, handled, and smelt enough to satisfy us with this very odd and very nasty vagary of tropic nature; and as we did not wish to become faint and ill between the sulphureted hydrogen and the blaze of the sun reflected off the hot black pitch, we hurried on over the water-furrows, and through the sedge-beds to the farther shore—to find ourselves, in a single step, out of an inferno into a paradise.

LIST OF BEST BOOKS ON SCIENCE AND INVENTION

ABBOTT, A. V.	<i>Telephony</i>
ADAMS, WALTER POYNTER	
	<i>Motor-car Mechanism and Management</i>
ALEXANDER, J.	<i>The Conquest of the Air</i>
ATKINSON, P.	<i>Electricity for Everybody</i>
BALL, SIR R. S.	<i>Story of the Heavens</i>
BATESON, W.	<i>Materials for the Study of Variation</i>
BICKERTON, A. W.	<i>The Romance of the Earth</i>
BONNEY, T. G.	<i>Volcanoes</i>
BREWER, ROBERT W. A.	<i>The Motor Car</i>
BRUNCKEN, E.	<i>North American Forests</i>
BURR, W. H.	<i>Ancient and Modern Engineering</i>
CHANUTE, OCTAVE	<i>Progress in Flying Machines</i>
CHATLEY, HERBERT	<i>The Problem of Flight</i>
CHEEVER, G. B.	<i>Wanderings in the Shadow of Mont Blanc</i>
CLODD, E.	<i>The Childhood of the World</i>
COLLINS, A. F.	<i>Wireless Telegraphy</i>
COOLEY, T. M. (Ed.)	<i>The American Railway</i>
COPE, E. P.	<i>The Origin of the Fittest</i>
DAMON, W. E.	<i>Ocean Wonders</i>
DANA, E. S.	<i>Minerals and How to Study Them</i>
DARWIN, G. H.	<i>Tides and Kindred Phenomena</i>
FLAMMARION, C.	<i>The World before the Creation</i>
FLEMMING, J. A.	<i>Waves and Ripples in Air, Water and Æther</i>
GEIKIE, SIR A.	<i>Geology</i>
GIBERNE, AGNES	<i>The Romance of the Mighty Deep</i>
GRAY, ASA	<i>Darwiniana</i>
GRIMSHAW, ROBERT	<i>Shop Kinks</i>
GUILLEMIN, A.	<i>Wonders of the Moon</i>

HARTWIG, G.	<i>The Sea and its Living Wonders</i>
HASTINGS, C. S.	<i>Light</i>
HERBERT, H. A.	<i>Triumphs of Science</i>
HOLDEN, E. S.	<i>The Sciences</i>
HURST, G. H.	<i>Theory of Color</i>
HUXLEY, THOMAS	<i>Essays and Addresses</i>
INGERSOLL, ERNEST	<i>Old Ocean</i>
JACOBY, H.	<i>Practical Talks by an Astronomer</i>
JEANS, J. S.	<i>Waterways and Water Transport</i>
KENNELLY, A. E.	<i>Wireless Telegraphy</i>
LANGLEY, S. P.	<i>Aerodynamics and Internal Work of the Wind</i>
LANGLEY, S. P.	<i>The New Astronomy</i>
LOWELL, P.	<i>Solar System</i>
MACOMBER, H. E.	<i>Stories of Great Inventors</i>
MAXIM, SIR HIRAM STEVENS	<i>Artificial and Natural Flight</i>
MAXWELL, C.	<i>Electricity and Magnetism</i>
MENDENHALL, T. C.	<i>Century of Electricity</i>
MOFFETT, C.	<i>The Locomotive Engineer</i>
MONCRIEFF, A. R. H.	<i>The World of To-day</i>
NEWCOMB, SIMON	<i>Popular Astronomy</i>
OSBORN, H. F.	<i>From the Greeks to Darwin</i>
OXFORD, H.	<i>Modern Optical Instruments</i>
PACKARD, A. S.	<i>Life of Lamarck</i>
PERCIVAL, A. S.	<i>Optics</i>
PRESTON, T.	<i>Theory of Light</i>
PROCTOR, R. A.	<i>Light Science for Leisure Hours</i>
PROCTOR, R. A.	<i>Other Worlds than Ours</i>
RAYLEIGH, LORD	<i>Theory of Sound</i>
RICHARDS, J.	<i>Machine Construction</i>
SERVISS, G. P.	<i>Astronomy with an Opera Glass</i>
SHALER, N. S.	<i>Outlines of the World's History</i>
SHALER, N. S.	<i>Sea and Land</i>
TAIT, P. G.	<i>Light</i>
THOMPSON, S. P.	<i>Light, Visible and Invisible</i>
TRAVERS, M. W.	<i>Experimental Study of Gases</i>
TYLOR, E. B.	<i>Anthropology</i>
TYNDALL, JOHN	<i>Forms of Water</i>
TYNDALL, JOHN	<i>Fragments of Science</i>





